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EDITOR'S PREFACE

This issue of the Yale Psychological Studies comprises two investigations made by candidates for the degree of Doctor of Philosophy under the direction of Charles H. Judd, former Director of the Yale Psychological Laboratory, now Director of the School of Education, University of Chicago. The present editor is responsible, however, for the editing of the manuscripts in preparation for the press.

TABLE OF CONTENTS

EXPERIMENTAL ANALYSIS OF THE WRITING MOVEMENT. By Frank Nugent Freeman, Ph.D., Assistant Professor of Educational Psychology, University of Chicago.... 1

EXPERIMENTAL ANALYSIS OF FORMS OF REACTION MOVEMENT. By Robert Day Williams, Ph.D., Associate Professor of Psychology and Education, Pomona College 55

EXPERIMENTAL ANALYSIS OF THE WRITING MOVEMENT[1]

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The experiment here reported consisted in an analysis of the handwriting movement of adults and of children by measurements of the size, speed and pressure of writing. By an interpretation of the results some of the psychological factors in the writing process and in its development have been determined. Writing is characterized by a decided rhythm which is more pronounced in the developed than in the undeveloped movement. In this as well as in other ways the movements by which the successive parts of a complex letter or series of letters are produced are united in such a way as to indicate that writing psychologically is not a succession of separate acts, but is an organized process in which individual elements have their place in the larger units of letters, words or groups of words. The component elements in the process come to be treated not as individual strokes or movements but rather as stages in the progress of the organized whole. The writing of children stands, however, in contrast to more developed writing in that it is less rhythmical, less organized and less automatized. That the child gives more continuous attention to the details of the writing movement is inferred from the fact that the movement is more uniform in speed throughout the different parts of the letter.

I. THE PROBLEM

The writing movement may be analyzed in two ways. In the first place the number of component movements—finger, hand, arm, etc.—may be determined and their nature investigated as in the experiments of Judd (**11**) and Obici (**17**); and in the second place the characteristics of the total resultant movement may be investigated. The present report deals with an investigation of the second type. The characteristics of the writing movement which are here studied are the speed, pressure and size of writing, and their relations to each other. Taken together

[1] A condensation of a thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Yale University, in May, 1908.

they furnish a good objective characterization of the writing movement. Such a study was made in order to determine the stages and course of development of the writing movement. A characterization of writing has often been sought in terms of the external form. The latest use of external form as a basis for study has been made by Thorndike (**19**) and Ayers (**3**) in their construction of scales for the measurement of the excellence of handwriting.[2] The present investigation, however, aimed to determine the differences in writing at different stages of its development in terms of the motor coördination by which it is produced. In this report a method for such a study is described and some comparative results of its application to the writing of adults and of children are given in order, as just stated, to ascertain the course of development of the movement. The application of the method to the study of the development of the writing movement is by no means complete and the writer plans to continue this study, and to present further results in the near future.

II. HISTORICAL SKETCH

A report of the experiments may be prefaced by a brief discussion of previous investigations in the experimental analysis of the writing movement by methods of the same type as the one here used. The discussion may be divided into two parts, concerning first, the investigation of the speed of writing, and second, of the pressure and speed together.

A study of the speed of finger and hand movements of different degrees of complexity, including the writing movement, was made by Jack (**10**). The movements had three degrees of complexity: first, simple flexion and extension of a single finger; second, a straight movement with the pen involving several fingers; third, an ordinary writing movement. The distinction between the second and third types is not altogether clear except, perhaps, that the latter included curves as well as straight lines. The method was to require the subject to trace the lines on a piece of smoked glass carried on one prong of a

[2] The writer has also prepared for publication in the near future a scale to be included in *The Teaching of Handwriting,* Houghton Mifflin Co., Boston.

vibrating tuning fork. The problem was to discover the modifications in the different types of movement with differences in age, education and manual skill. The result in general was that old age, lack of education or of manual skill, as well as certain pathological conditions, affected unfavorably the complex movements to a far greater extent than the simpler ones. The simple flexion and extension movements were made with practically the same rapidity by all classes of subjects and also with the right and left hands.

The speed of writing movements was more extensively studied by Binet and Courtier (**4**). These authors used the Edison pen. This is an apparatus by means of which a needle is driven downward by a rotating eccentric at a rate of 1,000 strokes per minute. Thus when one writes with the Edison pen a dotted line is traced, and the distance between the dotes indicates the speed of the movement. There are two defects in this method. In the first place the pen weighs about a quarter of a pound and the conditions are therefore not normal. In the second place, there is no record of the time of pauses. The results were as follows. The speed was greater when the writing movements were large and when they were accustomed movements than in the contrary cases. The direction in which the most rapid movements were made was the diagonal from lower left to upper right. The middle of the stroke was more rapid than the beginning and the end, connected writing was faster than disconnected, and intentional increase in speed corresponded to a decrease in size. A change in direction was accomplished by a reduction in speed, the amount of reduction being proportional to the angular change in direction. The more conditions which had to be satisfied by the movement, the slower it was. There was in general found to be a uniformity in speed variations in similar movements.

The relative speed of a writing movement in different directions was studied incidentally in connection with a general investigation of voluntary movement by Woodworth (**21**). He found that the most rapid movement was a side to side forearm movement and that the vertical finger movement was much slower.

The relative speed of finger, wrist and arm movements in different directions was investigated by McAllister (**12**). He used two methods. In the first the movements of the finger were recorded by the breaking of an electric circuit at the beginning and the end of the movement. The subject moved with his fingers the upper end of a vertical rod pivoted in the middle, the lower end of which released the contact. By the second method the speed of the movement was recorded by an electric spark produced by an induction coil, which passed from the pen to a metal sheet underneath the paper. The paper was covered with a coat of lampblack and the sparks were recorded as dots on the line of the writing. The defects of this method are first, that the possibility of a shock introduces a distraction; and second, that the time of pauses, as in Binet and Courtier's experiment, could not be recorded. McAllister found that movements in the direction from lower left to upper right and the reverse direction were the fastest, and that the arm movement was somewhat faster than the finger-wrist movement. He also found that the direction of a movement was unintentionally diverted in the direction of the greatest ease.

A piece of apparatus based on the same principle and called a graphometer was constructed by MacMillan (**13**). This consisted essentially of a small disc containing a groove along one of the radii and pivoted in the center so that the groove could be set in any direction. At each end of the groove were contacts and an electric circuit was made when the stylus touched either of these contacts. MacMillan, like Woodworth, found that the most rapid movements were made by a side to side arm and wrist motion.

The pressure of writing was first analyzed by Goldscheider (**8**). The method was to record the pressure by means of a tambour upon which the writing surface was supported. Goldscheider found that there is a characteristic form of pressure curve for the different letters and strokes and concluded that the sensations of pressure form an important means to the recognition and control of the writing movement.

Gross (**9**) analyzed the writing movement as a means to

clinical diagnosis. For comparison he studied a number of normal individuals. The apparatus used was Kraepelin's writing balance (*Schriftwage*). This consists essentially of a small table resting on the short arm of a lever, the other end of which records upon a kymograph. By adding a time line on the drum the total speed and average speed per letter may be measured. Gross confirmed Goldscheider's result that the pressure curves from a given individual for a given letter were uniform and that the corresponding pressure curves from different individuals presented great similarity. The pressure in general was higher on the down stroke than on the up stroke. Exceptions occurred, however, at the beginning and end of a letter or group of letters. The pressure showed a more abrupt release at the end than was the on-set at the beginning. There was a gradual increase during the course of writing of a series of letters or figures. The speed and size of characters had an intimate relation and tended to vary together. In other words, the total time of a character tended to remain constant and the writing manifested a rhythmical character. In the course of the writing the speed, pressure and size increased together. This was attributed to an increasing nervous excitation (*Anregung*). The same fact appeared at the beginning of writing and was attributed to the initial impulse (*Antrieb*). The author found greater variation in the length of the pauses between the strokes than in the duration of the letters themselves. He confirmed the result found by Jack, that there is greater difference between individuals in the complex than in the simpler strokes and that in pathological cases the differences due to education and skill tend to disappear.

The same method and apparatus was used by Diehl (**5**), who carried on his investigation for the purpose of testing and completing Gross's determination of the normal type. Diehl found in general a similar relation between the three elements, speed, pressure and size, as was found by Gross. An increase in the general nervous excitation or activity (*Anregung*) produced an increase in the speed, pressure and size. An increase in the mental difficulty attending writing, such as writing characters in the reverse order, produced a decrease in the speed and size and an

increase in pressure. Voluntary increase in speed produced a decrease in size and an increase in pressure. The changes in the last two instances are the same except for speed, which in the latter case is subject to voluntary control. An analysis of the two cases shows that an increase in effort produces a decrease in size and an increase in pressure.

This effect of effort upon writing has been determined incidentally in connection with other investigations. Urbantschitsch (**20**) found that stimulation by a high musical tone produced a crowding of the letters together and a decrease in size, accompanied by a feeling of constraint and inhibition, while a low tone produced the opposite effect. Meyer (**16**) found that an increased effort of attention produced a decrease in the size of writing and concluded that this was a special instance of a general increase in muscular tension which accompanies an effort of attention. Downey (**6**) reports an increase in pressure accompanying an increase in the difficulty of the attendant mental operation. The changes in writing with practice and facility consist, on the other hand, according to Diehl, in an increase in speed and a decrease in pressure and size. The author does not attempt to interpret these changes.

A similar investigation was carried on by Mayer (**14**). Mayer confirmed in general the results of the above-mentioned investigators and in particular the conclusions in regard to the relationship between speed, pressure and size. He attempts to explain the effect of practice upon these elements. He concludes that in the case of practice there is present a high dgree of effort and that this effort is directed toward a production of relatively high speed. In the case of unskilled writers this effort does not produce a decrease in size because they are unable to make the required forms in a small compass. With increasing skill this decrease is brought about. This explanation, however, does not take account of the fact, which is well established, that an increase in effort produces an increase in pressure. A more probable explanation would seem to be that with an increase in practice the acquirement of speed is attained with less and less effort. With increasing skill this is accomplished by economizing

on size. In other words, a decrease in size may be due to other factors than increased effort. The decrease in pressure is explained by the greater ease consequent on practice.

The rhythm of writing was studied by Margaret K. Smith (**18**) and Awramoff (**2**). Miss Smith used no special apparatus, but Awramoff used one which recorded the pressure by a combination of the registering devices of Goldscheider and Kraepelin, and the speed by a system of contact lines. The pencil in passing over these contact lines successively made and broke an electric circuit. Speed determination by such means is not accurate however, since the number of contacts per unit of length varies greatly with the angle at which the stroke crosses the contact lines.

Both authors found writing to be characterized by decided rhythm. This rhythm, however, is the result of development and is characteristic to a very limited extent of the writing of children. Awramoff describes the difference by saying that adults write a letter or series of strokes with a total unitary innervation (*Gesammtinnervation*), while children write with a separate impulse for each stroke. In terms of pressure the writing of children showed an individual pressure curve for each stroke, while in the case of adults the pressure throughout a letter or word had a single point of culmination to which it rose and from which it fell.

The effect of an imposed rhythm upon writing was found to be an increase in the quantity, usually accompanied by a decrease in the quality, of the writing. That is, each writer has his natural speed at which he can write best. He may learn, however, to modify the natural rhythm to a certain degree. The effect of a well chosen imposed rhythm upon children's writing was to organize it and render it more like the writing of adults.

III. APPARATUS AND METHOD

The apparatus and method utilized in this experiment were the same as those used by the author in a preliminary experiment on writing reactions, already reported in these studies (**7**). The apparatus was designed to measure the speed and the pressure

of writing or of a graphic movement. The speed was measured by a method based on the kymograph principle. That is, under the sheet of paper on which the reactor wrote there traveled a strip of paper and the record of the writing was taken on this strip through a carbon paper or, in the present experiment, a typewriter ribbon. In order to determine the speed of the strip, an electric marker was made to write tenths of a second on it. By this means the speed of the whole or any part of a letter might be accurately measured, and the duration of pauses in the movement determined.

In order to determine the details of the speed variations of writing, each letter written by the subject was divided into parts 1 mm. in length. This was done by means of a pair of sharply pointed dividers. The method is not strictly accurate but if applied with care will give results sufficiently exact for the present purpose, and the probable error of measurement was not great enough to render uncertain the conclusions which were drawn. This division of a letter gave also a basis for the measurement of size. This element of writing was not, however, treated independently, but only in its relation to the other elements of speed and pressure.

The pressure was recorded by a combination of the apparatus of Goldscheider and Kraepelin. That is, the writing was done over a small table which rested on the short arm of a lever. The movement of the longer arm was transmitted by means of a tambour and was recorded on a long strip of smoked paper which ran with approximately the same speed as that of the speed strip. Upon this pressure strip there was also a time marker indicating the same intervals as that on the speed strip. The advantage of this arrangement in comparison with those of previous investigators is that the pressure record may be accurately correlated with the speed record and thereby with the letter itself. Without this correlation it is a matter of guess work to determine what part of a letter corresponds to any particular part of a pressure curve.

An unimportant change in the author's previous method of driving the apparatus was introduced. This consisted in connect-

ing the driving shaft with the shaft of the machine shop below the experimenting room. This had the advantage of giving a more uniform motion than that which was obtained by the electric motor used in the previous experiment. This regularity of motion made it unnecessary to be particular that the writing movement was directly under the time marker.

The details of the method of measuring the speed records is as follows. The primary record, that is, the paper on which the reactor wrote, is placed over the strip on which the speed record was taken in the same relation in which they were when the writing was done. The records then appear as shown in Figure 1.

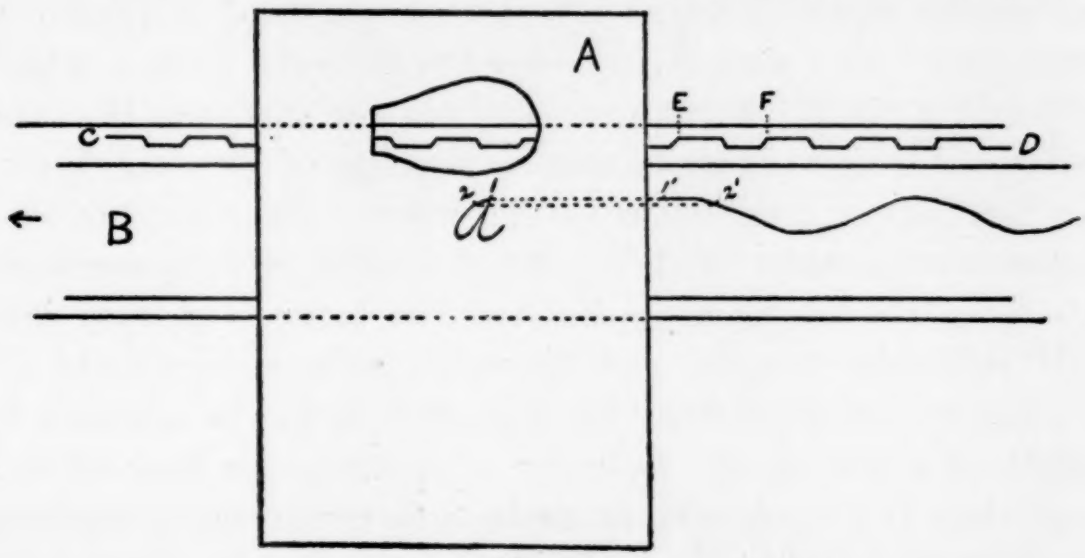

Figure 1.

The primary sheet showing the letter as written is indicated by the letter A, the speed strip by the letter B, the time line by CD, one unit of which is represented by the distance EF. The first millimeter length of the letter to be measured is represented by the distance between the points 1 and 2. The points on the time line which correspond to these two points are found by drawing horizontal lines from 1 and 2 respectively until they cross the speed curve. The line from point 1 should, of course, meet the beginning of the speed curve. If we now measure the horizontal distance between the points 1′ and 2′ we have a distance through which the strip travels during the writing of the first millimeter section of the letter. This, however, is subject to a correction due to the fact that the pencil altered its horizontal position during the writing of the section in question. Since the direction

of movement of the pencil was the same as that of the strip, the amount of horizontal pencil movement must be added to the horizontal distance on the strip in order to obtain the actual distance through which the strip traveled. We now must divide this distance by the distance which represents 1/10 of a second in order to turn it into time units.

Since these operations require great accuracy of measurement, a piece of special apparatus was constructed for the purpose. This apparatus is shown in Figure 2. It consists essentially of a vertical and horizontal scale which can be applied to the records. The vertical scale consists of a sliding glass plate moved by a micrometer screw by means of which one may read to 1/50 of a millimeter. This plate, E, is fastened to the metal piece, I, which slides in a tightly fitting groove, J, in the carriage, D. The millimeter distances may be read on the edge of the piece, I, and the fractions of a millimeter on the screw. The horizontal distances are measured by sliding the glass plate with its carriage, D, along the horizontal scale, A. The latter is divided into half millimeter lengths, and by means of a vernier scale, F, divided into twenty-fifths of a centimeter, it can be adjusted to tenths of a millimeter. In order to facilitate the finer adjustment there is a supplementary carriage, G, which may be clamped to the scale. The larger carriage, D, may then be adjusted by means of the screw, H. A magnifying glass set over the scale makes the reading easier.

The primary sheet is held in place by four flat discs which can be raised from the surface of the board, in order to insert the paper, and lowered again by turning the handles, K. These operate two rods upon which are eccentric cams. The cams raise the discs which are drawn down again by springs. The glass plate slides easily over these discs. The strip containing the speed records is adjusted by means of the rod, C, and a similar one at the other end of the board.

The method of operation is as follows. The glass plate is placed above the letter upon the primary sheet. The horizontal and vertical position of the first point on the letter is then determined by reading the horizontal and vertical scales respectively.

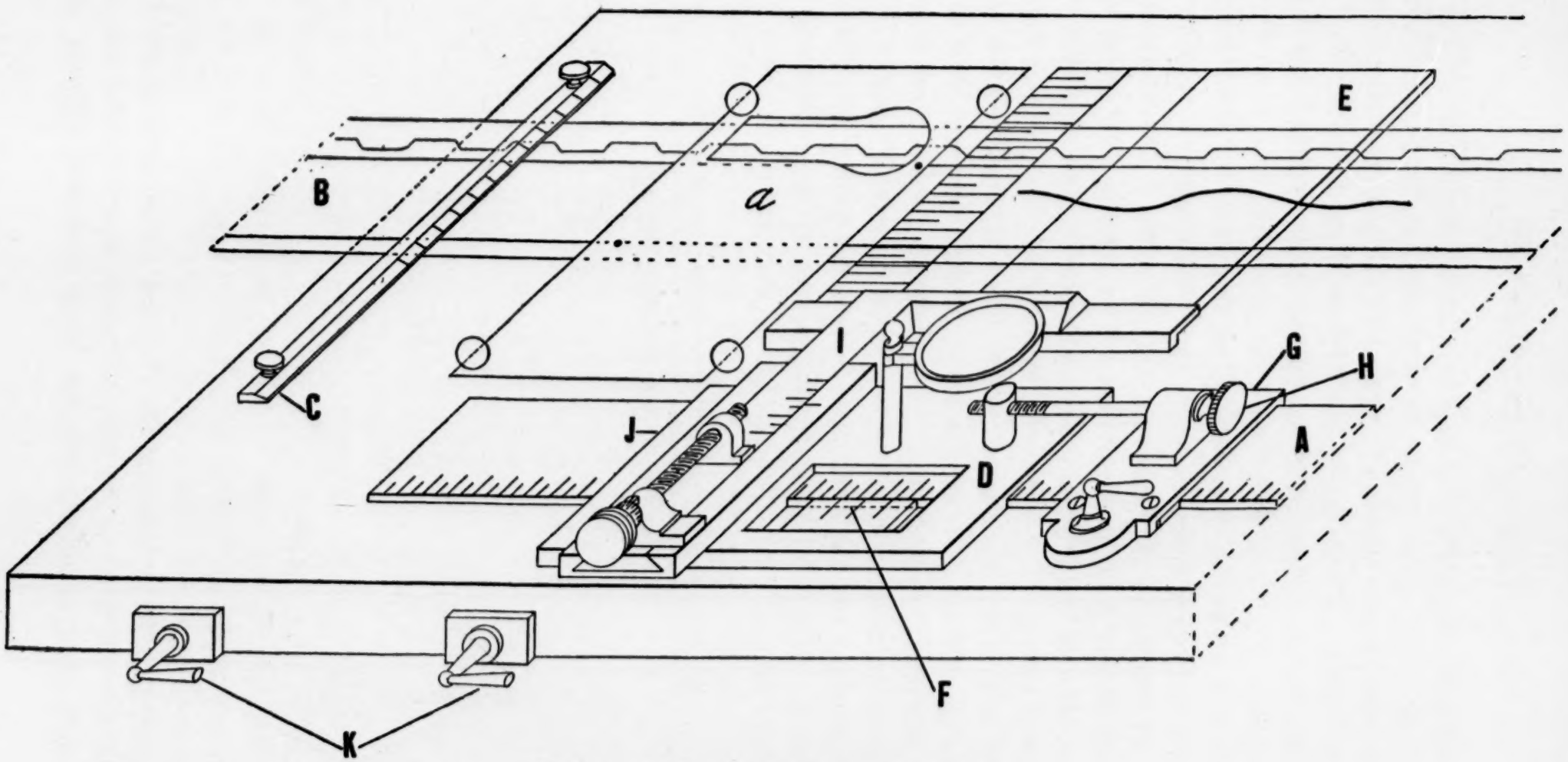

FIGURE 2—View of measuring apparatus.

The same is then done for each of the succeeding points of a letter. By means now of the vertical measurements, the points on the speed curve which correspond to the points on the letter may be found. By means of the horizontal readings the corrections for the movement of the pencil out of the vertical line may be determined. Thus, after the letter itself has been gone over, the plate is set at the first vertical reading and the point found on the speed curve which is on the same horizontal line with this. This, of course, is the beginning of the curve. The horizontal reading of this point is then taken. The plate is then set at the second vertical reading and the corresponding point found on the speed curve. The horizontal reading of this point is taken and so on for the rest of the curve. Each successive horizontal reading is subtracted from the one following it, and the differences corrected by the amount of horizontal displacement found in measuring the letter. The length of a unit of time line is then measured and the horizontal differences of the speed curve divided by this unit. The typical series of measurements is shown in Table I.

TABLE I

Illustration of the readings and operations involved in measuring the speed of the first two divisions of a letter

No. of division points	*Vertical reading on letter*	*Horizontal reading on letter*	*Differences in Horizontal reading*	*Horizontal measure on strip*	*Differences in Horizontal measure on strip*	*Corrected differences*
	mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
1	15.25	9.43		41.36		
2	14.45	9.38	—.05	43.42	2.06	2.11
3	14.00	9.36	—.02	44.03	.61	.63

	Dist. per 1/10 sec.	*Time per mm. in sigmas*
1		5
2	3.80	56
3	3.80	17

In order to present the results of these measurements graphically a curve is drawn, the base of which represents the successive millimeter distances of the letter and the altitude the

corresponding times in thousandths of a second. Such a curve (of the letter "o") is shown in Figure 3. The interpretation of this curve indicates that the reactor took considerable time (105 σ) to get started and to traverse the first section of the letter. The pencil then moved at an average rate of 1 mm. in 17 σ

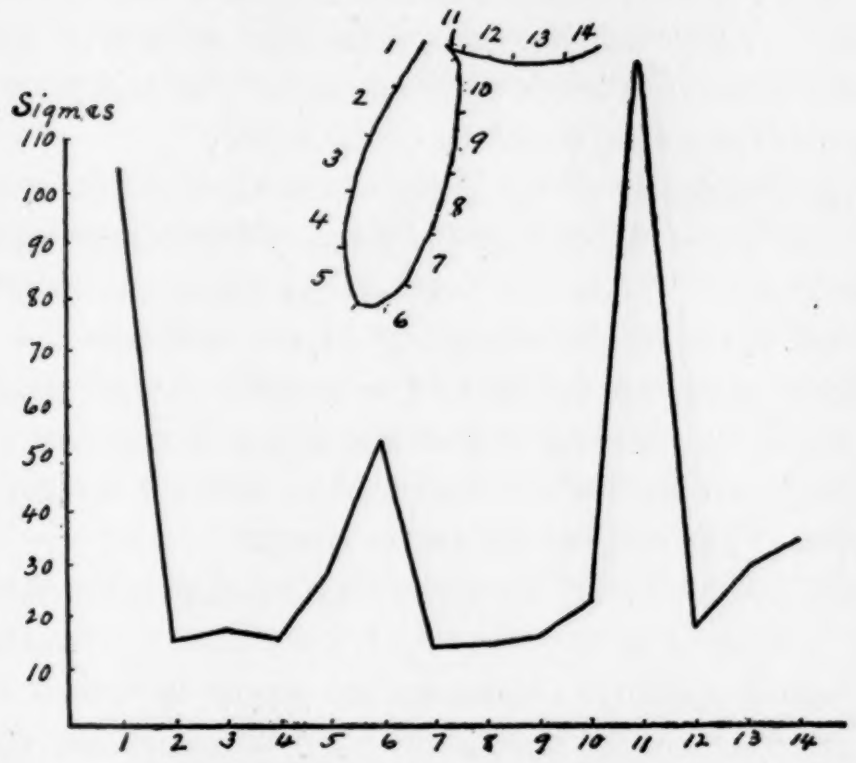

FIGURE 3—Speed curve of letter "O."

until it came to the curve at the base of the letter. The section at this point took 53σ—three times as long as the average millimeter on the down stroke. The up stroke was still faster than the down stroke. The turning point at the top of the stroke was slow however, occupying 124 σ. The last outward stroke was rapid. This was the typical record of the speed changes of the movement during the writing of a letter.

The pressure curve from the letter "o" by the same reactor is shown in Figure 8, in the appendix. The pressure curves are to be read from right to left. This curve can be correlated with the speed curve by reversing the process used in measuring a letter. In that case we found the time represented by a given distance on the strip by dividing this distance by the distance for one tenth of one second. Now in order to find the distance on the pressure record which corresponds to the time of

a given section of the letter, the distance for one tenth of one second on the pressure record is multiplied by the fraction of a second which represents this time. We may thus determine the points on the pressure curve which correspond to the successive points of the written letter. In this way, in the present instance, the position on the pressure curve of three points was determined. These are the end of the first millimeter distance, the bottom turn of a letter and the top of the upstroke, corresponding to divisions 1, 6 and 11 of the letter.

From an inspection of the pressure curve it will be seen that the pressure increased during the first millimeter to almost its maximum amount. Upon the down stroke the pressure decreased. It increased again at the beginning of the upstroke but fell to the minimum about the middle of this stroke. It then steadily increased while the readjustment at the top of the stroke and the final outward stroke were being made, reaching its maximum on the latter. The drop at the end is abrupt.

The methods here used for analyzing writing movements may be briefly compared with those which have been previously used. The only other methods known to the writer by which a speed analysis of the writing movement may be made are those of the Edison pen used by Binet and Courtier (**4**), the spark method described by McAllister (**12**), and writing over contact lines described by Diehl (**5**) and Meumann (**15**). The present method possesses the advantages in comparison with that of Binet and Courtier, first, that the conditions are more normal (since the Edison pen weighs a quarter of a pound and contains machinery in rapid vibration); second, that it permits the measurement of the duration of a pause; and third, that it permits a more exact measurement of the more rapid parts of a letter. The advantages over the spark method are similar to those over the Edison pen with perhaps even greater emphasis on the first point. The defect of the system of contact lines is that the units of distance which are measured by it are not uniform. This criticism was made above.

The only method of analyzing the pressure curve with which the present method may be compared is that of Diehl and of

Meumann. The other methods of recording pressure, for example those of Goldscheider (**8**) and Kraepelin, furnish no means of determining the correspondence between the pressure and the parts of the letter. The correlation between the pressure curve and the written letter is in any case only as exact as the speed analysis of the letter. Since the latter, in the method of Diehl (**5**) and Meumann (**5** and **15**), is inaccurate the correlation of the pressure curve with the written letter is correspondingly inaccurate.

The reactors in the experiment consisted of four adults and ten children. Of the adults, three were graduate students, T. T. G., R. D. W., and F. N. F., and the fourth a college senior, D. H. Of the children, five were boys and five girls. The ages ranged from 9 to 15. C. K., 14 years, was in the second year in high school. H. H., 13 years, was in the first year in high school. M. G., 13 years, and G. B. 15 years, were in the eighth grade. O. B., 14 years, and E. C., 12 years, were in the sixth grade. C. N., 11 years, and A. S., 11 years, were in the low sixth. E. H., 10 years, was in the fourth, and M. H., 9 years, in the third grade. C. K., H. H., O. D., C. N., and A. S. were boys and M. G., G. B., E. C., E. H., and M. H. were girls. For the opportunity of working with the children the writer is indebted to Mr. Harry Houston, Supervisor of Penmanship in the New Haven Schools, who arranged to have the children come to the laboratory and was present himself at several of the experimental periods.

There were first measured two and in some cases three specimens of each letter of the alphabet of the writing of a single reactor, F. N. F. This was done in order to determine the differences and relationships between the different letters of the alphabet and thus to avoid generalizations which might rest on a study of part of the letters. Means was thus furnished also of choosing letters for use with the other subjects which might represent different typical facts in regard to their writing. From each of the remaining subjects then, records of the writing of three or four letters were obtained. In the case of adults there was some variation in the particular letters used, but with the

children the same were used for all, namely, the letters "a," "r," "f," and "h." The word "American" was chosen to test the letters a and r written in combination and each reactor also wrote his own name. Mr. T. T. Giffin made a short investigation of the letters "a," "b," and "c" in his own writing in connection with the course in experimental psychology at Yale. The writer wishes to thank him for the use of the results of this study.

This may appear to be a small number of letters to measure, but the time required in the measurement of the records was so great that it was not practicable to use a larger number. It was therefore thought preferable to make an intensive and exact study of a few letters than an inexact study of a larger number. The writer plans to simplify the method of procedure without sacrificing accuracy and to extend the study over a wider range.

Besides writing in the ordinary manner it was planned that each reactor should write under varied conditions. These conditions consisted in writing much larger than usual and writing between two horizontal lines, in order to test the effect on the writing of differences in size and of the addition of certain external limiting conditions. It was also planned to study the relations between letters written separately and in combination in a word, but this purpose was only to a limited extent carried out. Reactor R. D. W. gave a complete series with the letters "r," "e," and "m" and D. H. a complete series with the letters "a," "e," and "n." Reactor T. T. G. wrote the letters "a," "b," and "c," but only in his natural writing, that is, without variations. F. N. F. gave a complete series except that he did not write between lines. The letters which were written large were "b," "r," "f," and "h," and the letters in combination (in his given name) were "r," "a," "n," and "k."

An effort was made to have all of the subjects write in as natural a manner as possible. This was probably successful in the case of adults and of some of the children. The chief tendency which had to be combated with the latter was one toward slow, painstaking writing, such as one would put in a copy book. Such writing would furnish a profitable subject of study but would be unfavorable to the type of comparison made in the

present experiment. Reactors M. G., G. B., O. D., and E. C. seemed to the experimenter to write in this unnatural manner and the records of the speed of their writings was not measured in detail, only the total speed and the average speed per millimeter being taken.

IV. RESULTS AND DISCUSSION

The discussion of results will be divided into three main parts, taking up first, the average speed per millimeter of the various letters; second, the characteristic changes in speed in the different parts of the letter, which may for convenience be spoken of as the speed curve; and third, the pressure and the pressure curve. The writing of children and adults will be compared on the basis of this analysis. Under these heads also will be made a comparison of the different letters with one another, of letters written larger than usual and of those written between limiting lines.

We will first take up the consideration of the average speed of letters written under different conditions and by different adult subjects. We are dealing with the average speed per millimeter and not with the speed curve. The first result deals with the relation between the size and the average speed of different letters of the alphabet in the writing of F. N. F. The size is measured by taking the length of the line which the pencil traced in making the letter. A comparison was made by putting the letters in two lists, the first being arranged in the order of size and the second in the order of speed. These lists are given in Table II.

It will be seen that, in general, the order of the letters in the two columns is the same. That is, the larger letters are also the more rapid. The degree of correspondence may be worked out by the "r" method of correlation, according to which the degree of correlation is expressed by differences in the gradation from zero to one. The correlation in the present instance is found to be .83, which indicates a close relationship between speed and size of the letters. Some deviation from exact correspondence exists, it is true, but this may be at least partly explained by the differences in the complication of the letter and the

TABLE II

A comparison of the order of the letters on the basis of size and of speed

	Letters in the order of their average speed Reactor F. N. F. Time in sigmas per mm.		*Letters in the order of their size Reactor F. N. F. mm.*	
1	j	15	k	36
2	g	17	g	36
3	f	18	f	33
4	l	20	p	33
5	k	21	h	31
6	p	21	j	30
7	d	22	t	29
8	h	22	m	27
9	z	22	q	27
10	q	23	d	26
11	t	23	y	26
12	i	24	z	26
13	y	25	b	24
14	e	27	w	21
15	m	28	l	20
16	s	30	s	18
17	w	30	u	17
18	b	31	n	17
19	v	32	v	16
20	u	33	e	16
21	x	33	a	15
22	n	35	i	14
23	o	37	x	14
24	a	38	o	12
25	c	42	r	12
26	r	42	c	11

consequent difficulty in making it. For example, the "k," which is the largest letter, is especially slow at the last turn and this puts it lower in the speed column. Again, "j," which is sixth in the order of size, is first in the order of speed because of its simplicity. The differences which occur may therefore be accounted for on the basis of other factors and the relation between speed and size comes out very prominently.

This correspondence between the speed and size of writing appears also from a comparison of the same letters written, first, in the ordinary size and, second, larger than usual. The comparison for the three adult subjects is shown in Table III. On the right appears the percentage increase in the size of the letters when they were written large and on the left the percentage decrease in the time per millimeter (or the increase in speed) of the large letters.

There is in these cases a decrease in the time per mm. in each case of an increase in size. The decrease in time ranges

TABLE III

Comparison of the time in sigmas per mm. of letters written normal size and large

Reactor	Kind of letter		Comparative times per mm.				Comparative size in mm.			
	Normal	31	42	18	22		24	12	33	31
	Large	15	24	14	16		45	21	51	45
%	Decrease	52	43	22	27	% Increase	88	75	55	45
D. H.			*a*	*e*	*n*		*a*	*e*	*n*	
F. N. F.		*b*	*r*	*f*	*h*		*b*	*r*	*f*	*h*
	Normal		40	48	47		17	11	15	
	Large		28	26	30		30	20	26	
%	Decrease		30	46	36	% Increase	76	82	73	
R. D. W.			*r*	*e*	*n*		*r*	*e*	*m*	*a*
	Normal		75	44	50		10	15	19	
	Large		22	15	15		31	35	78	40
%	Decrease		71	66	70	% Increase	210	133	310	

from 22 per cent to 71 per cent and is greater when the normal letter was unusually slow. The decrease in time is also greater the greater the increase in size. See for example, the great decrease in time in case of the reactor R. D. W.

This tendency to increase in speed with an increase of size is also shown by comparison of the total time of the letters of each sort. This comparison is made in Table IV, which refers to the same letters as those in Table III. There are four cases in which there is a decrease in the total time of a letter when the size increases. The increase in total time when it occurs is very small compared with the increase in size.

TABLE IV

Comparison of the total time in sigmas of letters of normal size and written large

F. N. F.	*b*	*r*	*f*	*h*	*D. H.*	*a*	*e*	*n*	*R. D. W.*	*r*	*e*	*n*
Normal	733	476	587	668		688	524	706		753	664	955
Large	642	487	693	675		844	515	775		679	549	1149
% Inc.	—12	2	18	1		23	—2	10		—10	—17	20

A comparison may now be made between the average speed of normal letters and of those written between lines. Only two adult reactors gave data for such a comparison. The results are shown in Table V. The lines between which the reactor wrote were so placed in the case of R. D. W. that he wrote much larger than usual. The intention of this arrangement was to prevent the reactor from disregarding the lines, but it also introduced another factor, that is, the increase in size. The amount of increase in size is shown on the right-hand side of the table. For R. D. W. this is great enough to necessitate a correction of the

figures; that is, we must calculate the percentage change in time per mm. which would result from the increase in size of the letters (calculated on the basis of Table III) and by subtracting this from the actual percentage change in time get the increase which is due to the introduction of the lines. We have, therefore, in the table, first, the actual percentage change in time per mm., then the percentage change which would be produced by the increase in size and finally the corrected increase in time.

TABLE V

Comparison of time in sigmas per millimeter of letters, normal and between lines, showing increase in time.

	Time per mm.				*Size in mm.*		
R. D. W.	*e*	*m*	*r*		*e*	*m*	*r*
Normal	45	50	75		15	19	10
Between lines	49	37	41		22	45	25
% Change	+11	—26	—45	% Increase	47	137	150
% Change corresponding to inc. in size	—23	—31	—51				
Corrected change	+34	+5	+6				
D. H.	*e*	*n*	*p*		*e*	*n*	*p*
Normal	48	48	28		11	15	21
Between lines	74	73	44		11	14	32
% Increase	54	52	57				

The increase in time is very pronounced for D. H. and for the letter "e" of R. D. W. The lack of a pronounced increase for "m" and "r" of R. D. W. may be accounted for by the fact that the normal writing of this reactor was unusually slow as compared with the writing of the other reactors and with his own large writing. This then would tend to reduce the effect of lines in decreasing the speed of the writing.

We turn now to a consideration of the average speed of the writing of children. The data for discussion are shown in Tables VI and VII.

Table VI gives the time per millimeter of the normal letters written by the various children and the average for all of the children, as well as the percentage change in time of the letters written large and between lines. The corrected change in time for letters written between lines was calculated by the method already described for R. D. W.

Table VII gives the size of the letters written under the different conditions for the various children. The averages, and

TABLE VI

Time in sigmas per millimeter of the children's writing.

Reactor	*Normal*				*Large*				*Between Lines*				*In Name*	*In word "American"*
	a	*r*	*f*	*h*	*a*	*r*	*f*	*h*	*a*	*r*	*f*	*h*		
H. H.	65	70	37	41	40	54	40	35	55	72	43	47	41	43
C. K.	74	94	48	52	44	56	31	37					69	58
M. G.	117	118	92	98	84		55	63	117	125	75	78	105	105
G. B.	117	96	50	48	100	63	36	43	92	83	61	53	78	
O. D.	115	188	103		118	145	89	123	142	165	86	116	74	164
E. C.	174	187	184	156	181	164	117	106	182	257	125	116	124	170
C. N.	178	145	102	90		121	87	109	149	185		93	89	134
A. S.	141	152	116	115	110	85	52	62	106	130	60	52	84	125
E. H.	109	90	70	54		116	54		105	98	64	55	64	70
M. H.	47	64	42	45	52	54	36	45	84	103	64	72	71	57
Avg.	113.7	120.4	84.4	77.7	91.1	95.4	59.7	69.2	114.7	135.3	72.3	75.8	79.9	102.9
% Change..					20	21	29	11	+ 1	+12	—14	— 3		
% Change corresponding to inc. in size									—15	—13	—47	—16		
Corrected change in time									+16	+25	+33	+13		

TABLE VII

Size in millimeters of letters of the children's writing.

Reactor	*Normal*				*Large*				*Between Lines*				*In Name*	*In word "American"*
	a	*r*	*f*	*h*	*a*	*r*	*f*	*h*	*a*	*r*	*f*	*h*		
H. H.	12	8	25	25	28	16	30	38	31	20	53	48	60	51
C. K.	11	12	21	19	25	20	37	35					54	43
M. G.	16	11	26	26	24		38	37	23	16	39	43	20	48
G. B.	14	12	25	23	31	29	50	40	19	16	37	40	25	
O. D.	19	11	28		23	11	28	30	20	14	45	34	40	42
E. C.	14	12	23	27	23	25	32	42	22	19	36	37	24	34
C. N.	20	16	23	24		26	40	51	24	16	41	42	42	41
A. S.	16	11	28	21	21	17	36	36	27	17	54	60	21	16
E. H.	17	12	23	24		14	43		16	14	46	44	23	24
M. H.	15	12	26	26	27	18	32	35	21	17	47	49	22	13
Avg.	15.4	11.7	24.8	23.9	25.3	19.6	36.6	38.2	22.6	16.6	44.2	44.1		
% Increase					64	68	48	60	47	42	78	85		

the percentage increase in size of the letters written large and between lines. These figures are used as the basis for the calculation of the corrected change in time for letters written between lines as given in Table VI.

The speed of the children's writing is markedly less than that of adults. The speed of the "r" for example is 42 σ per mm. in the case of F. N. F. and 64 σ per mm. in the case of the most rapid children's writing. The slowest of the children's writing gives 188 σ for this letter. Similarly, the speed of "f" for F. N. F. is 18 σ and for the children 37 σ to 184 σ. For the "h" the corresponding times are 22 σ, and 41 σ to 156 σ respectively. The same relation may be found between the writing of the same letters by the other adults and that of the children; it is not necessary to make a detailed comparison. The only striking exception is the case of the "r" written by R. D. W. This is exceeded in speed by the writing of two of the children, but the large "r" of R. D. W. is more than twice as fast as any of the large "r's" written by children.

There is still a greater difference in speed in favor of adults when the letters are written large. That is, adults show a proportionally greater increase in speed with the increase in the size of the writing.

As a class then the writing of children is much slower than that of adults. There is not found in the present experiment, however, a uniform gradation in speed for the children of advancing age, although the ten children do fall into several fairly well defined groups. H. H., C. K., and G. B., the older children, are comparatively fast writers. M. G., O. D., E. C., C. N. and A. S. write more slowly while, finally, the two youngest, E. H. and M. H., write comparatively fast.[1] This anomaly of fast writing of the younger children is probably due partly to the fact that the children did not all apprehend the problem in exactly the

[1] Other and more comprehensive tests of the writing of children in the elementary school of the University of Chicago and in the public schools of more than fifty large cities have revealed a more regular but not entirely uniform progression in speed. The speed is affected by the quality of the writing and probably also by the style of teaching adopted by the individual teacher.

same way. That is, some evidently aimed very much more at accuracy of form than others. Their writing had almost the appearance of the copy book style. The other children, on the other hand, wrote more fluently and carelessly. This may be due partly to a difference in teaching. A further possible cause of difference lies in the fact that the older children had reached a higher stage of development in which they were able to write a series of letters with a unified movement. Their chief advance then would be represented not by an improvement in the writing of isolated letters but of letters in a series. The present experiment deals almost entirely with the writing of isolated letters. This may not bring out the chief difference between the writing of the younger and the older children.

The difference in speed of the letters of the alphabet due to their normal differences in size is also a factor in the writing of children. If we compare for example, the speed of the "a" and the "r" with that of the "f" and "h," we find that the latter are written much more rapidly. The difference is not so great, however, as in the case of adults. That is, there is not so much tendency in the writing of children to maintain a constant time for letters when the size varies.

The relative decrease in speed of the children's writing between lines is on the whole probably less than that in the writing of adults. It is greater than that of the adult reactor R. D. W., but this is probably, as indicated above, not a fair representative of the average change in the case of adults. In comparison with the other adult reactor, D. H., the writing of children between lines showed very much less decrease in speed.

The discussion thus far has dealt with the average speed of the letters. We now come to the analysis of the speed of the various parts of a letter, represented in the speed curves. The results are not susceptible of presentation in tabular form, but must be given by an analysis of typical individual speed curves. A comparative analysis may first be made of the characteristics of the different curves, and the relation of these characteristics to the forms of the various letters and to the different conditions of writing in the case of one individual. The comparison may

then, secondly, be extended in the same way to the writing of different adults and of children. An attempt will be made in connection with the analysis of the results to make an interpretation of them by relating them to other facts of reaction and movement. The question may be raised, for example, as to how far the changes in speed are due to mechanical or to psychological factors. We will now proceed with the discussion of the writing of the individual subjects.

Figure 4, in the appendix, gives a typical speed curve of each letter of the alphabet as written by reactor F. N. F. An analysis of these curves shows that there is always considerable time consumed in starting the stroke and bringing it to its normal speed. There is also a retardation at the end of the letter. This slowness at the beginning, while characteristic of every letter, showed great variation in amount for the different letters. The duration ranges in the whole series from 51 σ in the case of the letter "j," to 128 σ in the case of "b." The variation in the speed at the beginning is shown even in different cases of the same letter. The slowness at the end is not a uniform characteristic of all of the letters.

No principle which may account for the initial variation is discoverable. If the letters are arranged in order according to the speed of the first part of the letter, this order has no evident correlation with that which is made on the basis of the size of the letter. We cannot say, therefore, that either the average speed or the size of the letter has a noticeable effect on the time of the first part of the stroke, for it will be remembered that there was a correlation found between average speed and size. The complexity of the letter might conceivably have an effect upon the speed of the beginning, and if we allow for this factor, there might be a relation between the initial speed and the size of the letter in combination with the complexity. That is, theoretically we might assume that the retardation at the beginning would be greater the smaller the letter and the greater the complexity. Even with this modification, however, the two series do not show any apparent correlation.

We may ask then what the explanation of the initial delay

may be. There is, doubtless, a slight mechanical inertia which would cause a somewhat gradual increase in speed at the beginning of the letter. The great variation in the initial speed, however, shows that this factor, in the cases before us, accounts for only a small part of the phenomenon. Evidently there are cases in which the writer is prepared to make a stroke as soon as the pencil touches the paper, and in these cases inertia plays but a small part. If we turn to a possible psychological factor, we must exclude any which involves a reaction time. We might conclude, for example, that the initial period represented the time of reaction to the cue furnished by the contact of the pencil with the paper. The time of the first millimeter, however, is less than 100 σ in all but three of the letters and this obviously excludes such an interpretation. The assumption that originally such a reaction took place and that the adult habit is a survival of this procedure is probably also excluded by the fact that a time sufficiently long to admit of a reaction is not present in a nine-year-old child. If a reaction to contact-stimulus were the original basis then of this delay, it must have disappeared before that age. We can only say that the initiation of the stroke includes a movement of the pencil down upon the paper and then across its surface. A slight incoördination between the two parts of the act would account for the delay at the beginning of the letter. The lack of accurate adjustment would also account for the variation in the time of this initiatory stroke. Since the initial delay is too short to be interpreted as reaction time, we cannot speak of the initial pressure as an initiatory control, but only as a possible report control, that is, a sensation which reports the completion of an intended movement. This will be again referred to in a discussion of the pressure.

The retardation at the end of the letter is still more variable than the delay at the beginning. In fact, it is sometimes absent altogether. When it is present, however, it apparently indicates that stopping a movement may be as definite an act as starting one. It was found in the preliminary experiment (**7**), for example, that a reaction by stopping a movement was longer than one by starting. But in finishing the movement of writing a

letter we have not the same sort of reaction as when a movement is stopped at a given signal since in writing a letter the end of the movement is anticipated during the writing. We have, however, on the objective side, as already indicated, and also on the subjective side, a definite fact representing the cessation of the movement. The movement does not merely stop but it is stopped. This is often connected with the consciousness of the "rounding up" of the letter, as though one would say, "so much is finished." This is, doubtless, much more characteristic of some writers than of others.

An examination of the speed curves (Fig. 4) shows that there are other points at which there is a definite retardation of the movement, and a comparison of these points with the letters themselves indicates that they come at places of change in direction of the stroke. We may, for convenience, call these places in the letter "turns," that is, points where the stroke turns a corner. Binet and Courtier (**4**) and Jack (**10**) mention these points of retardation and state as a general principle that the retardation is greater the sharper the turn, or that the speed is proportional to the radius of the curve. This rule would hold roughly if the delay in speed were due to mechanical factors. There is, doubtless, some approach to this general principle, but it does not apply in the wholesale fashion indicated by such a simple statement. There are other factors which influence greatly the amount of retardation. A measure of the difference which is due merely to the difference in angular change may perhaps be seen from a comparison of the "l" and the "t." We have here two turns which are radically different in form. The sharp turn at the top of the "t" is, to be sure, slower than the more rounded turn at the top of the "l," but the difference in this case is slight. The difference is much less than many differences in the case of strokes having the same sort of turn. Compare, for example, in this respect the first turns of the "a," "d," and "g," all of which are of the same form. The relative retardation of these is quite different.

The last example shows that we must look to other conditions than the immediate character of the stroke to explain the speed.

The part of the letter which follows any particular part under consideration is of importance. In the present instance, for example, the latter part of the letter "g," that is, the lower loop, doubtless has an effect upon the time of the first turn. This is but an example, of which many others will be found, of the fact that the act of writing a letter is a unitary thing, each part influencing every other part. In particular, the following parts of a letter influence those which precede. This is closely related to some of the results found in the preliminary reaction experiment (**7**). For example, the time of a reaction was very much lengthened when the stroke which constituted it was required to extend to a certain point, or to follow the course of some geometrical figure. In terms of adjustment, the motor mechanism had a different set according as the the later movement was of one sort or another. In psychological terms, the anticipation of a given type of later movement affected the previous attitude.

The same difference as that found in the last mentioned letters is also found in the comparison of the "i" and the "j." That is, with two turns exactly similar the amount of retardation is different.

If we compare the turns in the "m" and "n" with those in "u" and "w," a striking fact appears. Whereas, in the former, the sharp turns (at the bottom of the letters) are much slower than the rounded ones, in the case of the latter this difference disappears or is reversed. The sharp turns at the top are no slower than the rounded turns at the bottom.

The turns represent, therefore, something besides mere points requiring a mechanical readjustment of the stroke. They doubtless represent to a large degree the points of division of the letter from the point of view of the movement and the perception processes. That is, a letter is represented to us, not as a uniform whole, but as composed of certain subordinate units. If the division point between these units occurs at a turn, the mechanical tendency to a retardation will be reinforced. Otherwise, the movement will proceed past the turn with little more retardation than is produced by mechanical conditions. In

the case of the "g," for example, it is very probable that the first enclosed loop, which it has in common with the "a," and the other loop which extends below the line, represents two such units of the letter. The development of these units of movement is characteristic of adult writing, as we shall see later.

In confirmation of the principle that certain turns show a retardation out of proportion to the change in direction of the stroke, we may point to the last turns in the letters "b," "f," "k," "o," "v," "w," and "s." From the point of view of form there is no reason for the extreme retardation of these turns. That is, we cannot assign a mechanical cause for it. They have the common characteristic, however, that they mark the completion of a certain definite part of the letter. In addition to this, most of them demand a rather delicate adjustment of the stroke so as to meet a certain point or line. These two factors together comprise the condition which causes the slowness of the movement. The first factor is the same as that which, according to our hypothesis, caused retardation at the end of the letter, and the second is related to the retardation of a reaction, already referred to, caused by the necessity of a later adjustment. Binet and Courtier (**4**) refer to this same fact when they state that the more conditions which are set for the movement, the slower it is.

The slowness at the second turn of the "z" may perhaps be ascribed partly to the fact that it completes one section of the letter as well as to the fact that it is immediately followed by another pronounced readjustment in direction. That is, the next stroke consists in a rather abrupt turn and the formation of a loop. The latter condition (a sharp turn followed closely by another) is still more strikingly exemplified in the letter "r." The first turn of this letter is no sharper than the top turns of the "i" and the "j," for example, but it is uniformly an extremely slow stroke. In analyzing the letter we see that this particular turn is immediately followed by two other readjustments in direction. In preparation for these, the movement makes an unusually long pause. Another example is shown in the comparative speed of the last upstroke of the "g" and the "q." In

the latter it shows the delay which is produced by the more delicate adjustment which concludes it.

The effect of the succeeding part of a letter upon that which precedes is well brought out, too, by a comparison of the first turn in the letters "a," "d," "q," and "g." This turn is exactly the same in all these letters from the point of view of its external form. It may be readily seen, however, that it is progressively more rapid in the successive letters, in the order named. This corresponds to the fact that there is also a progressive increase in the size of the letters. Evidently then, the total size of the letter has an influence upon the speed of certain definite parts. The individual parts do not stand by themselves, but are united throughout the whole letter in the total movement which produces them, so that each part is influenced by the others.

We may now turn our attention to a comparison of the speed of the relatively straight strokes of the different letters. Binet and Courtier (**4**) stated that the longer the stroke, the faster was the movement which made it. This appears to be true in the examples which are before us. In the form of the above statement, however, it is susceptible of an explanation which our curves do not justify. That is, it is clear that from the mechanical standpoint a stroke might gather speed the longer it persisted. We would then have a shorter stroke and a longer one exactly similar so long as we compared identical distances. That is, the longer stroke would increase in speed in the same manner as the shorter one and then continue its increase merely because it lasted longer than the other. This, however, is not the case. The longer strokes reach their characteristic speed in the same space as the shorter ones, and this speed is greater in the former than in the latter. This is shown by the fact that the speed curves for the straighter strokes are practically level, and that those for the longer ones are on a lower level than the others. Compare, for example, the similar strokes of the letters "e" and "l," "i" and "j," "b" and "f," and "u" and "y."

If we compare the smaller and the larger letters with respect to the speed of the turns, we find here also the same relation

as in the case of the straight strokes. That is, the longer letters are faster throughout. This enables us to analyze the difference which we found between the average speed of the large and the small letters. This might possibly have been due to the fact that the longer letters have a greater proportion of straight strokes as compared with the turns, and that they, therefore, have a greater average speed since the straight strokes are more rapid than the turns. This, it is true, must contribute to the difference in speed, but that it is not the whole or even the chief factor, is seen from the present analysis. That is, the elements in the letter which are strictly comparable are made in different time when the letter is large or small. In the large letter there is a quickening of the whole movement, an evident tendency to rhythmical writing in the sense that different strokes, though of differing length, tend to be made in the same time.

We may further compare the speed of the up and down strokes. Awramoff (**2**) states that down strokes are the faster. In our own preliminary experiment (**7**) the relation of the speed of vertical lines in the upward and downward direction was studied in the case of the four reactors. There was found to be a large variation. The reactors formed a series. One of them made the up strokes markedly faster, and another the down strokes faster. The two other reactors made the one or the other faster on the average, but the difference was much less. One of the two latter was the reactor whose writing is the subject of this analysis (F. N. F.). In the preliminary experiment he made the up strokes faster than the down strokes in eleven cases out of sixteen. In writing the letters in the present experiment there are some cases in which the same relation holds, but there seems to be no uniform rule. There are many special conditions which affect the speed of the up or down stroke, so that any tendency which may exist toward a greater speed of the one or the other is covered up. For example, the main down strokes of the "d," the "f" and the "p" are the faster, but this difference may be assigned to the fact that these strokes have fewer conditions to meet than the up strokes, or that they are of greater length. On the other hand, the up strokes of the "i," the

"u" and the "z" are the faster. But in the case of the first two letters, these strokes are the longer, and in the case of the last one the up stroke has a freer course. There is therefore no clear evidence that either sort of stroke is more rapid than the other in the case of this reactor.

The relative speed of the strokes in the direction of the two diagonals, the upper left to lower right (represented in backhand writing), and the upper right to lower left, is shown in the letter "x." In accordance with the principle laid down by Binet and Courtier (**4**), Woodworth(**21**), McAllister (**12**), and McMillan (**13**), the latter is much the faster.

The letters "x" and "t" furnish an opportunity for a comparison of the speed of the stroke which the pencil traces through the air in making two parts of the letter, with the speed with which it makes the stroke itself. The average time per millimeter from the end of one stroke to the beginning of the next in these two letters was measured, and is indicated in the line which joins the corresponding points on the speed curve. It appears that the average speed of this free stroke is the same as for the part of the stroke immediately preceding and following it. This seems on the face to be a contradiction of the statement of Binet and Courtier that connected writing is faster than disconnected. The facts, however, are too fragmentary upon which to base such a conclusion, and it will be also noted that the parts of the letter which precede and follow the free stroke, are not so rapid as the ordinary straight stroke. This is doubtless due to the fact that there is here a readjustment in direction. We cannot, therefore, in the present case, draw any far-reaching inference.

An examination of the records of the other adult reactors will indicate the variations which may be expected to occur within the adult type and will give a broader basis for comparison of the adult with the child type. A few speed curves from the three other adults are shown as samples in Figure 5 in the appendix: "a" by T. T. G. (curve 68) and D. H. (curve 78); "b" and "c" by T. T. G. (curves 66 and 72); "e" by D. H. (curve 74) and R. D. W. (curve 85); "m" by R. D. W. (curve 87), "n" and "p" by D. H. (curves 76 and 79).

In discussing the differences between the speed curves of the different persons the difference in shape of the letters must be taken into account. Compare, for example, the shape of the "c" as written by F. N. F. and by T. T. G. Aside from the extra stroke, the latter has a sharper turn at the bottom than the former. Compare also the "a" of D. H. with that of F. N. F. and of T. T. G. There are here three degrees of angularity, from the writing of T. T. G. at one extreme to that of D. H. at the other. We should then expect to find, other things being equal, a corresponding difference in the amount of retardation at the turns. If the differences do not correspond, other things, that is the characteristic speed variations of the writers in question, are not equal.

It should be said also in discussing the retardation of the turns of a letter, that we should regard the relative and not the absolute speed of these parts. As a measure of retardation then, we shall take the quotient of the time of a particular slow part of a stroke divided by the time of the adjacent rapid part. In making this calculation we will not use the extremely low points of the curves of T. T. G. since the time these represent is probably too short.

From a glance at the general characteristics of the speed curves of the various reactors, it is seen that they conform to those already pointed out in detail in the case of one writer[3]. We find the gradual increase in speed at the beginning, the retardation at each change in direction, and in some cases, notably in the writing of T. T. G., a retardation at the end.

If we examine the writing of the four reactors we shall see that that of one, T. T. G., is angular, that of two, D. H. and R. D. W. is rounded, and that of the fourth F. N. F., stands midway between the two extremes. Parallel to these differences there is a difference in the average speed, T. T. G. writing most rapidly, D. H. and R. D. W. most slowly, and F. N. F. at a medium rate. The relative speed of the straight strokes and the turns varies in the same order. There is a relatively greater retardation at the turns in the writing of T. T. G., least in that

[3] See p. 13.

of D. H. and R. D. W., and an amount between these two extremes in the writing of F. N. F. That is, so far as we may judge from the the results of these few reactors, the relation between the speed of the straight strokes and the turns and the differences in speed for the different sharpness of the turns are the same when we compare the writing of different individuals as when we compare the writing of different letters written by the same individual. The same rule holds that the sharper the turn the greater the retardation. In regard to the relation between the differences in speed and the amount of retardation, however, the principle appears to be reversed. When we compare the writing of different individuals, the more rapid writing is characterized by greater retardation at the turns. That is, the difference in speed seems to be chiefly in writing the straighter strokes, whereas in the writing of a single individual an increase in speed in rapid writing occurs equally or nearly so in all parts of the letter. In other words, the same writer tends to preserve his characteristic writing rhythm at different speeds, while different writers who write at different speeds have also a different rhythm.

It was remarked above that the writing of T. T. G. is characterized by a marked retardation at the end of the letter. It will also be remembered that this writer has greater retardation at the turns. We may then say that he has a general habit of pausing, or at least slowing down the strokes at the end of strokes and of letters. This may be called a particular type of the writing habit, and goes in this case, at least, with an angular style and with generally rapid writing.

As was found in the case of F. N. F., there is no noticeable difference in the writing of other adult reactors in the relative speed of the up and the down strokes.

In discussing the writing of F. N. F., we have already compared the speed characteristics of letters of different sizes, as for example, the "a" and the "p."[4] We may also compare the speed of certain letters written by the adult subjects at one time in the usual size and at another time written larger than usual. Two

[4] See pp. 17-18.

typical records of letters written larger than ordinarily are shown in Figure 6, the letters "r" written by F. N. F. (curve 47), and "n" written by D. H. (curve 82). These show the typical relation of letters written in this way to the ordinary writing. A comparison of these curves with those of the records of the same letters, written by the same subjects, in the usual size, in Figures 4 and 5 shows that the same difference obtains here as was noted between different letters of different sizes. That is, in writing the larger letter, whether we compare different letters of different sizes or the same letter written now small and now large, there is a marked increase in speed throughout the letter, both on the straight strokes and at the turns. In other words, a writer tends to maintain the same writing rhythm.

The records from writing between lines are so meager that general conclusions cannot be drawn from them. The results from the three cases which are at hand are suggestive, however, and are illustrated in the sample record from the letter "n" written between lines by D. H., Figure 6, curve 75. A marked retardation in the speed is here evident, and it is also evident that practically all the excess retardation comes at the turns, that is, at the places where the stroke approaches the limiting line.

An illustration of the effect on the speed of writing a connected series of letters in a word is given in Figure 7. This is the record of the letters "Frank," part of the given name of the reactor. A comparison with the separate letters "r," "a," and "n" may be made by turning to the curves in Figure 4. The striking thing about the connected letters is the great uniformity in the speed changes of the successive strokes as compared with the changes in the same letters written separately. The amount of retardation at the turns in particular, is practically the same for the various turns of the different strokes. This is a good example of a sort of unity or uniformity in connected writing which consists in a marked degree of rhythm throughout. This rhythm is partly independent of the external formal character of the strokes and partly influences the character of the external form by reducing the differences among the various letters.

The pressure changes in adult writing are illustrated by the reduced reproductions of typical pressure curves from F. N. F., D. H. and R. D. W. shown in Figure 8. These curves are to be read from right to left. The dots on the curves represent certain stages in the letter. The first dot on the right represents the end of the first millimeter of the stroke, the succeeding dots represent the various turns, so that the parts between the dots correspond to the different strokes.

A glance at the various pressure curves makes it evident that there are regularly two points of high pressure in the letter, namely, the beginning and the end. There are exceptions to this rule, as at the beginning of the letters "h" and "t" (curves c and f, Figure 8). These are, however, distinct exceptions. The particular curves shown to illustrate the writing of D. H. do not show a marked high pressure at the beginning. The writing of this reactor is not in general, however, an exception to the rule. This high pressure at the beginning and the end of the letter occurs whatever the direction of the stroke may happen to be. It may be an up stroke, a down stroke or a horizontal stroke. It is evidently due, then, to the position of the stroke in the letter. An explanation for the high pressure at the beginning has been suggested in discussing the retardation at this part of the letter. On account of the insufficient time, the retardation and high pressure cannot be regarded as constituting an initiatory cue or control, but are probably due to the fact that the beginning of the stroke constitutes a point of adjustment between the movement toward the paper and one along the surface of the paper. The stroke along the surface of the paper is not a second movement, the initiation of which follows upon the sensation of pressure caused by the contact of the pencil with the paper, but part of a single movement which may be interrupted for a longer or shorter period by the lack of perfect adjustment to the position of the paper. This adjustment may be more or less rapid and perfect. The more rapid and perfect it is, the less will be the retardation and excess of pressure at the beginning of the stroke.

The pressure at the end may be related to the fact that there is

a progressive increase in pressure throughout the letter. This latter fact was noted by Gross (**9**). There is probably a general heightening of nervous excitation in the course of the writing. There is, however, a special increase in pressure just at the end. We found also that there is often a marked retardation at the end of the letter. The two facts are doubtless connected and are to be interpreted as meaning that ending a letter is a definite act psychologically and physiologically.

The above-mentioned pressure characteristics pertain to the letter as a whole and indicate its unity. There are also certain pressure changes which correspond to particular sorts of strokes. An examination of the pressure curves shows that there is, in general, a greater pressure on the down strokes than the up strokes. This fact was also pointed out by Gross. The rule, it is true, is not universal. There are variations between different letters and between different reactors, and limitations due to the position of the stroke in the letter. So, for example, the last stroke may be an up stroke and still have a high pressure. See the curve for the "h," curve c, Figure 8. Or the first stroke of a letter may be a down stroke but the initial pressure be so great that the subsequent part of the stroke decreases in pressure. Again, while a down stroke may in general be made with a high pressure, the last part of the stroke may decrease in pressure. Or the last part of an up stroke may increase in pressure in the same way. For this reason the division points on the curve do not always come at the crest or the valley. See the two "h's," curves b and c, Figure 8. Further, as was indicated in the preliminary experiment, there is often a slight rise in pressure at the beginning of a stroke, whether its direction be up or down. See, for example, the rise at the beginning of the "o," curve d, Figure 8. These variations are due to the relation of the different strokes to each other in the letter and are evidence of th oft-repeated fact that a letter is not merely a collection of strokes, but possesses a distinct unity.

There are also variations among different individuals in the relation of the pressure to the direction of the stroke. To R. D. W., for example, the rule applies but very slightly. There

is somewhat greater pressure on the down stroke, but not a great deal. This brings us to the query why any such relationship exists and why it varies with different persons. The difference might formerly have been explained as a result of convention. But shading on the down stroke is not now commonly taught or practiced with definite intent in the United States. Such shading might, however, explain the phenomenon among writers in Germany. A probable explanation is to be found in the manner of holding the pen and in the character of the movement from the mechanical standpoint. If we observe the position of the pen as we hold it in the orthodox way, we will see that it makes an acute angle with a down stroke of the writing. A movement made in this position by turning the fingers about the middle joints would, if the pen point were not against the paper, trace an arc of a circle. The chord of this arc would not be parallel to the surface of the paper but would be inclined toward it as we make a down stroke. When the pen moves across the surface of the paper we compensate for this tendency by an extensor movement of the first joints of the fingers and a drawing up of the thumb. The tendency to make the movement in a simpler way, that is, by a simple arc-movement about the middle joint, survives, however, in the increased pressure of the stroke.

Reactor R. D. W. held his hand over on the right side so that the pencil did not make an acute angle with the down stroke, and accordingly we find that he exerts practically the same pressure on the down as on the up stroke. The variation in pressure is then probably the function of the mechanical conditions of writing due to the manner of holding the pen, and to the character of the movement in relation to the structure of the hand.

Pressure changes during writing which have been described in the case of one reactor are characteristic of the others with the exception just noted. There are certain variations in detail, but the general principles hold good.

A pressure curve of a letter written large is shown from the writing of R. D. W. and D. H., and of one written between lines by D. H. (Fig. 8). The effect of the modified conditions is substantially the same for all the reactors. When the letters are

written large there is a greater difference between the maximum and minimum pressure of a letter than when they are written in the usual size. There is also more variation in the different parts. In the case of letters written between lines, the opposite effect may be seen. There is less difference in pressure in the different parts. In the latter case it is evident that greater care and closer attention is given to the form of the writing. In the former case, effort is put forth to write with greater speed, though the effort may be made without conscious attention. We may then assume, perhaps, that the attention is to some degree withdrawn from the form. If this inference is correct we may say that attention to form tends to a lack of differentiation in pressure and conversely that approach to automatic writing tends to differentiation in pressure.

In order to compare the writing of children with that of adults, a single letter is chosen, the letter "f." The speed record of this letter written in the usual way is taken from the writing of H. H., C. N., A. S., E. H. and M. H. (Fig. 9, curves 93, 104, 109, 121 and 115) and the record of the same letter written large and between lines is given for the last four reactors (Fig. 10, curves 105, 111, 123, 117 and 107, 113, 125 and 119 respectively). Pressure curves from the same letter for all five reactors are shown in Figure 11.

The most general facts in regard to the speed changes in adult writing appear also in the writing of children. There is a marked variation in speed in the different parts of the letter. The greatest speed is on the straight strokes and there is a more or less retardation at the turns. When we come to examine the children's writing in detail, however, marked differences appear. An examination of the curves from the children's writing reveals a great deal of irregularity, both between the writing of different children and in the writing of the same individual. Compare, for example, curves No. 104 and 109 from the writing of C. N. and A. S. (11 years of age) and curves Nos. 121 and 115 from the same letter written by E. H. and M. H. (10 and 9 years respectively). Although the latter two children are younger they have written the letters much faster than the first

two. The children, in general, showed in the experiment a tendency to write in what appeared to be an unnatural and unusually slow manner. But in the case of the reactors here under consideration, the supervisor of penmanship, Mr. Houston, was present and encouraged them to write freely until he obtained what he thought was their normal writing. We may assume then that the characteristics of this writing were not the product of the conditions of this experiment. We must seek a more general explanation.

There are three possible explanations for this difference between the writing of the different children. In the first place, it may be due to individual variation. This, however, is improbable, for individual variation is ordinarily greater in the writing of adults than of children, and the variation in the present instance is greater than that which we have found in the case of adults. In the second place, the difference may be due to differences in the stage of development, the earlier stage being characterized by greater freedom and less care for form than the later one. A failure to develop in the direction of increase of speed might also, as remarked above, be due to the fact that attention was being turned to the connection of the letters with one another. The third possibility is that the writing of a child is more variable than that of an adult. The same child may write now slowly and carefully, and now rapidly and carelessly, according as the conditions vary or his attitude toward the situation is different. His habit, according to this view, is not yet settled, and since it is in the plastic state it is much more susceptible to outside influences. Adults are also subject to such influence, but not to the same extent. On the basis of our present knowledge of the child's writing habit the third explanation seems to the writer to be the most probable.

The great irregularity in the writing of the same individual may be seen by comparing (Fig. 9) the speed of the different strokes in the writing of H. H., curve 93 and of C. N., curve 121; and of the first part of the letter with the last part in the case of M. H., curve 115. These examples are illustrations of the fact referred to in the last paragraph, that the same child may have

different types of writing. The extremely slow writing is evidently not due to the inability to make a single stroke more rapidly, but either to the difficulty of combining the strokes in a complex total movement, or to attention on the visual form to be made, thus introducing conditions which we have found to reduce the speed of the movement. These two causes doubtless are combined.

In spite of these variations, the children have, in common, one mark of uniform difference from adults. This difference is concerned with the relative speed of the straight strokes and turns. There is less retardation at the turns in the children's writing compared with the speed of the straight strokes. The form of the curve does not make this apparent; in order to get at the true relations one must compare the distance of the various parts from the base line. The difference between the writing of children and adults in the ratio of the speed of the straight strokes and the turns is then seen to be marked. Children have, then, a greater general uniformity of speed throughout the letter, so far as the influence of different kinds of strokes is concerned. That is, there is less difference on the average, between the speed of the straight strokes and the turns.

The curves 105, 111, 123 and 117 in Fig. 10 are records from C. N., A. S., E. H. and M. H. writing the same letter large. We have here evidence in confirmation of the position that the first two children are to be distinguished from the last two in the type of movement they employed. In writing large the first two modify the speed of their movement radically while the last two do not. The first two reactors, furthermore, modify the type of the movement so as to approach that of adults. That is, there is a greater difference between the speed of straight strokes and turns when the writing is large. The younger children had apparently written at about their maximum speed when they wrote the letter in the usual size. It may also be that the tendency to rhythm is less with them and their writing is therefore less modified by the increase in size.

There is a noticeable difference in the speed changes when the letters are written between the lines. The feature common to all the cases is the increased retardation at the turns where the

letters meet the line or a decrease in speed on the part of the stroke approaching this point or both. In the case of A. S. the approach only is slow. A very noticeable case of the retardation at the turn is seen in curve 107 from C. N. A marked case of retardation on the approach is seen in curve 119, from M. H. The lines were so placed that the letter was written considerably larger than usual. This caused it to be written more rapidly by C. N. and A. S., particularly the latter, and this counteracted the retardation due to the lines.

These results indicate then that a restriction such as limiting lines has a similar effect on the writing of children as on that of adults, that is, a retardation, particularly at and just before the point of finer adjustment.

The pressure of children's writing is illustrated by curves from five reactors, Figure 11. The pressure records of E. H. were too dim to be read. The division points on the curve represent the same points on the letter as in Figure 8. Where there are only three division points the last out stroke of the "f" was too short to be indicated.

The mean pressure of the children's writing is less than that of the adults, as shown in the accompanying table:

Adults

F. N. F.	9.5	D. H.	15.0
R. D. W.	13.5		

Children

H. H.	2 5—B	E. C.	4.5—G
C. K.	8.0—B	O. D.	14.0—B
M. S.	6.5—G	A. S.	7.0—B
G. B.	7.0—G	M. H.	9.5—G

The units are arbitrary. The letters on the right indicate the sex and show that this was not a determining factor. Too much stress is not to be laid on this difference in mean pressure because the children in these schools were drilled in the avoidance of pressure. The low pressure of H. H., the son of the writing supervisor, is significant in this regard.

In certain respects the pressure changes of children's writing are similar to those of adults. There is a gradual increase in pressure toward the end of the letter. There is usually a rise

in pressure on the down stroke and a fall on the up stroke. The curves from reactors A. S. and M. H. are exceptions to the rule in this respect.

The similarity of the records of some of the children to those of adults is also apparent. The pressure in the writing of H. H., C. K. and C. N., for example, increases and decreases in the same parts of the letter as in the typical adult writing. The entire release of pressure, however, is a mark of difference. In the writing of A. S. and M. H. the maintenance of the same degree of pressure for a continued period of time at the end of the letter is at variance with the adult type. In general then, the pressure of the children's writing varies from that of adult writing chiefly in that it is more irregular. This is evidence that the coördination has not yet attained stability and uniformity.

If we attempt to characterize the writing habit of children in comparison with that of adults, or in other words, if we describe the course of development of the writing habit so far as we may do so on the basis of the results of this experiment, we find in the first place that undeveloped writing is irregular. This irregularity is a matter of easy observation so far as the external form is concerned. We have here defined the irregularity in terms of the coördination. There is irregularity in the average speed and in the distribution of speed throughout the letter. For example, though the ratio between the speed of the straight strokes and the turns is less than in the writing of adults, though there is greater uniformity in this sense, this ratio is less constant than in adults' writing. There is greater change wrought in the coördination by changes in the outward conditions. The yet imperfectly formed coördination is unstable, having not yet acquired its fixed form.

Another characteristic of undeveloped writing which we have been able to define somewhat definitely, is the relative lack of rhythm. There is less tendency than in developed writing to increase the speed with an increase in size, whether of the same letter or of different ones. In writing letters larger than usual the adult increases the speed of the whole letter, while the child increases the speed of the straighter strokes.

We may venture to interpret the greater uniformity in speed in the writing of children as indicating that the writing process is a more continuous one than is the writing of adults. This continuity may be interpreted as giving evidence of more continuous and uniform discharge of nervous energy, or innervation. On the the mental side it doubtless corresponds to the more continuous and greater expenditure of effort throughout each part of the writing stroke; and to the application of a higher degree of attention to the visual aspects of the writing stroke during its production. This latter conclusion is supported by the experiments of Ahrens (**1**) and the observations of Schubert, whom he quotes, to the effect that the eye movements of children follow the course of the writing stroke more completely than do the eye movements of adults.

With the development of the coördination less attention is given to the visual aspects of the writing. The guidance or control of the movement must then be given over more largely to the kinesthetic sensations. This fact brings the points of motor readjustment in the writing into greater prominence. These are of course the points of division between the successive strokes. Furthermore, the control in developed writing is not only relatively less dependent on the visual and more on the kinesthetic sensations, but the attention is less directed toward controls of any sort. In other words the writing becomes more automatic in nature and comes more under the influence of the mechanical conditions of the movement. One of these conditions is the inertia which brings about a retardation in the speed of an object when the direction of its movement is altered. This factor again brings about a discontinuity in the movement by which the successive strokes are produced.

The results of this experiment, then, lead to the adoption of a point of view regarding the character of the nervous process by which the writing movement is produced which is at variance with the interpretation made by Smith (**18**) and Awramoff (**2**) on the basis of their experiments, and by Meumann (**15**) in his interpretation of children's writing. These authors hold that children's writing is a series of separate impulses or innerva-

tions (*Einzelinnervationen*), whereas in the writing of adults a number of successive strokes or letters is united by the fact that they are produced by a single impulse (*Gesammtinnervation*). On the contrary, the writing of children is less broken up into distinct strokes than that of adults. The fact that the pressure curves give evidence of at least as sustained effort as do the pressure curves of adult writing points to the same conclusion.

As there are characteristics of writing in successive stages of development which point to a breaking up of the continuity of the process, there are other facts which point to a progressive organization or unification. This appears in the more pronounced rhythm of developed writing and in the extent to which the speed and pressure of the individual strokes are modified by their relation to the other strokes which compose the letter or the word. This increase in the organization of the movement may be looked on as the positive result of the change in the object of attention, of which the negative result is the increased mechanization. The attention of the practiced writer is not narrowed to the portion of the stroke which is being made, but includes the word or group of letters of which the stroke which is being made is a part. That this inclusion in the attention of anticipated strokes influences the stroke which is in the course of being made accords with the fact which was discovered in the preliminary experiment (Freeman **8**), namely, that the speed of a reaction is modified by the anticipated later course of the movement.

This anticipation of letters and organization into groups accompanies the recognition of them as having meaning—that is, as being language symbols. The organization takes place primarily on the plane of the recognition of meaning, and secondarily in the motor process. This organization affects the series of innervations which compose the writing movement, not by making them into a total innervation, but by introducing modifications into the successive innervations. These modifications take the form of the development of rhythm, and of sundry retardations or accelerations of parts of strokes as the result of the anticipation of other strokes.

The statement that undeveloped writing is not organized into a complex habit so that the separate elements of movement can be relinquished to relative automatism does not mean that the child would not be able to make a single stroke by itself, not in a letter, much faster than he makes the parts of a letter. He could. But it is precisely the ability to make a stroke in a letter as though it were not restricted by its relationship to other strokes, and at the same time adjust it nicely to them, which requires the combination of automatism and control which the child cannot command. He must develop it by long practice, at first under the constant guidance of attention.

It would be out of place to discuss here any pedagogical applications of these principles, but one which follows directly from what has been said may be at least mentioned. It is unquestionably true, as Meumann (**15**) and Awramoff (**2**) hold, that since rhythm is one of the chief characteristics of the developed writing habit, to impose an artificial rhythm upon undeveloped writing will give it some of the characteristics of developed writing. It may do so at the expense of external form, however, if the precaution is not taken to suit the tempo to the ability and stage of development of the child.

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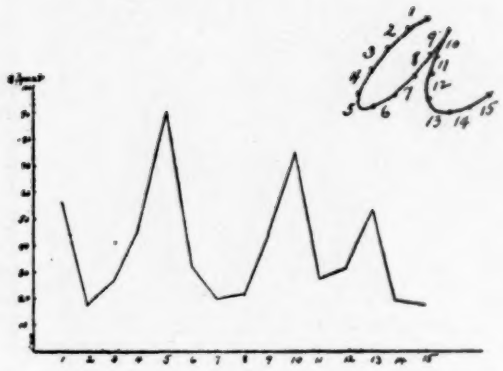
No. 3



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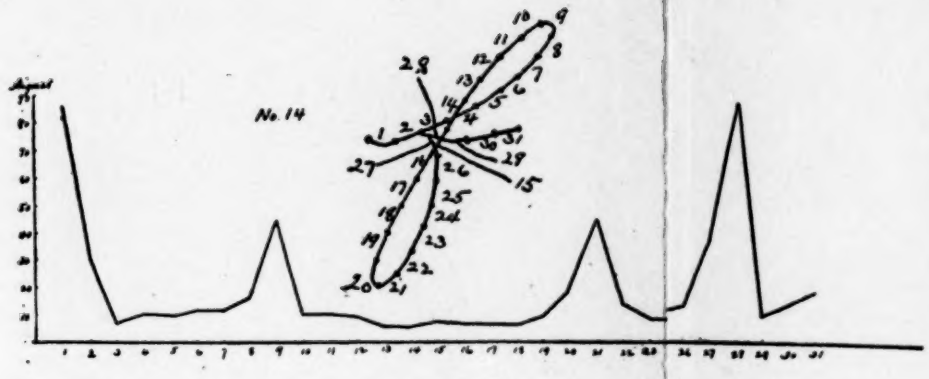
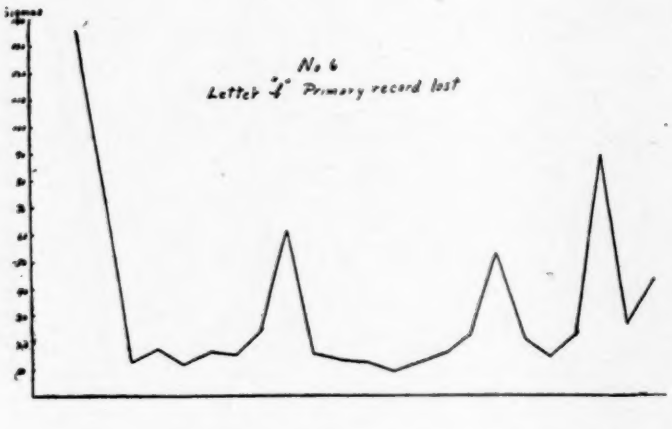
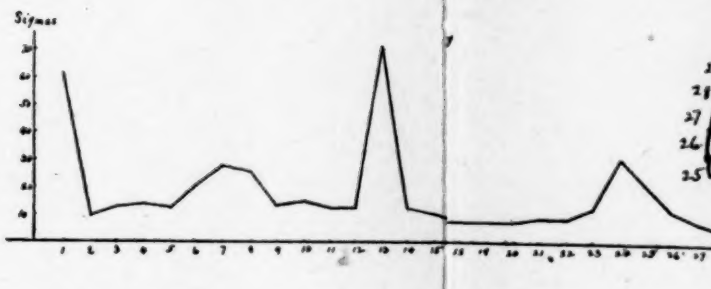


No. 6

Letter "d" Primary record lost





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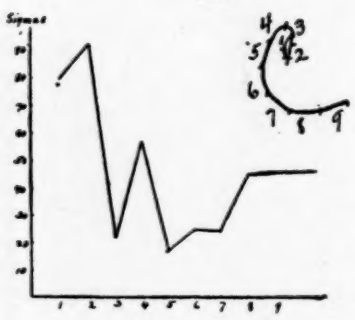

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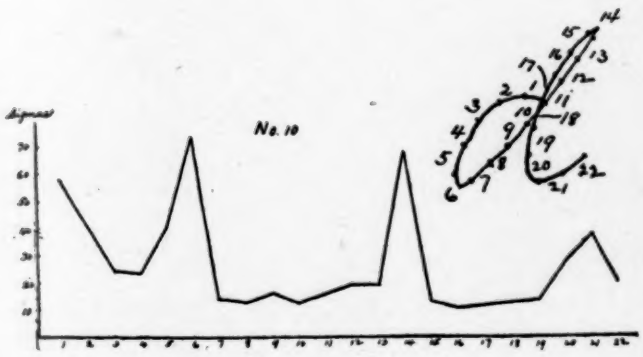

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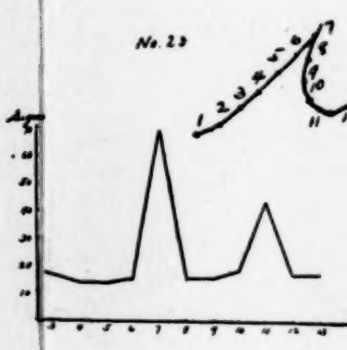

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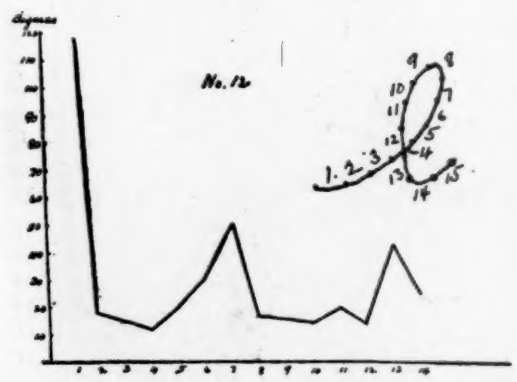

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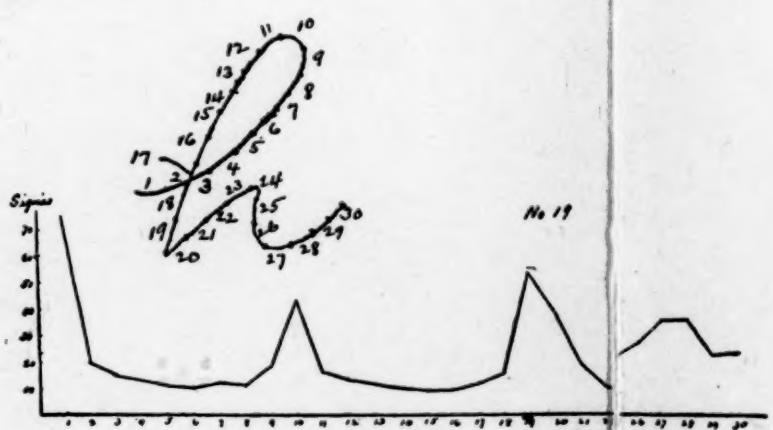
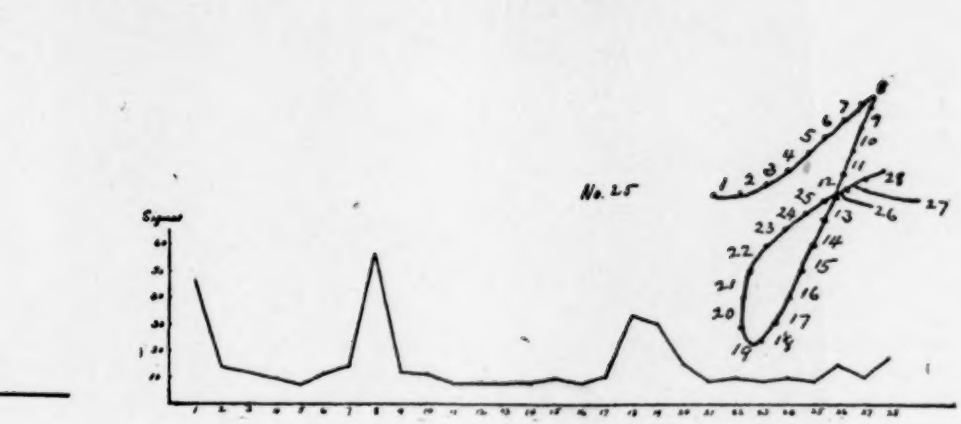
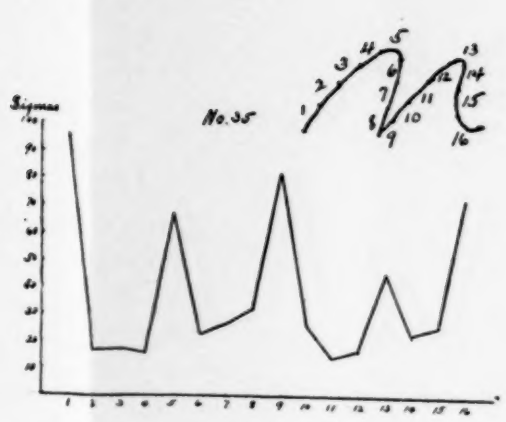
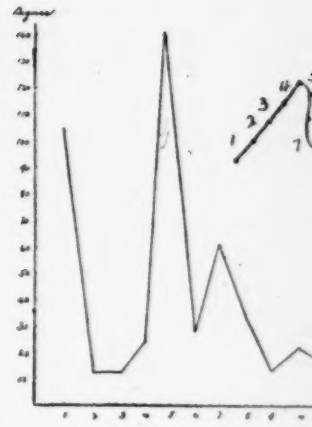
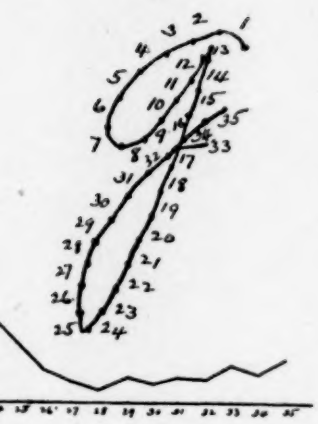
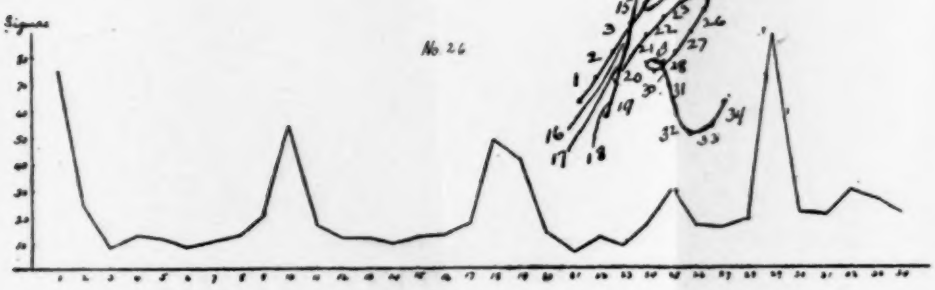


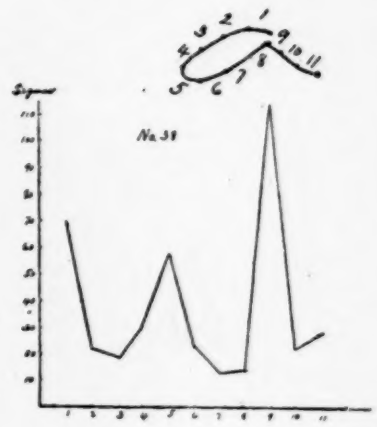


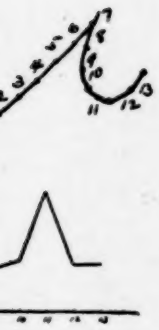


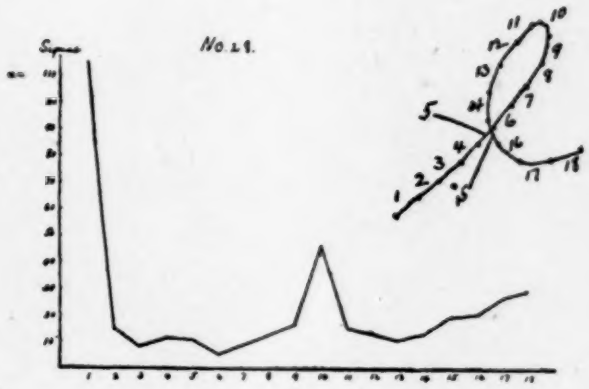


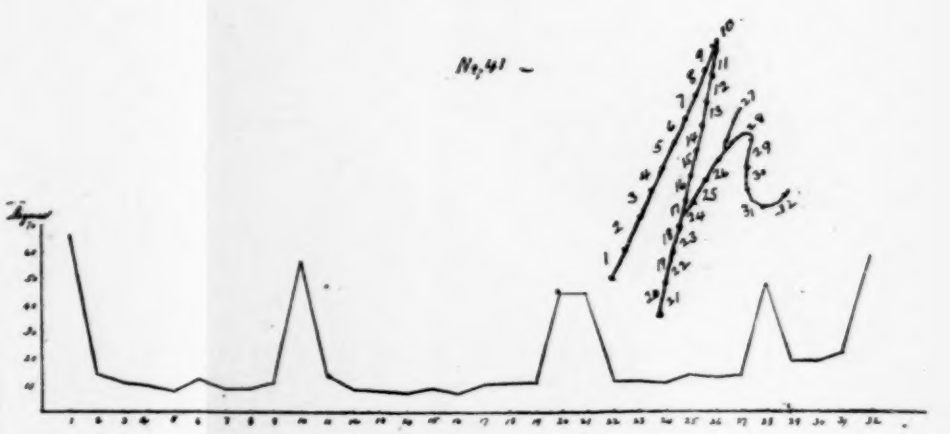


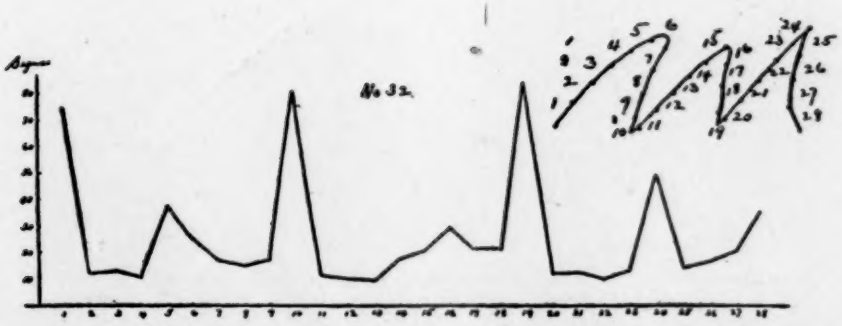












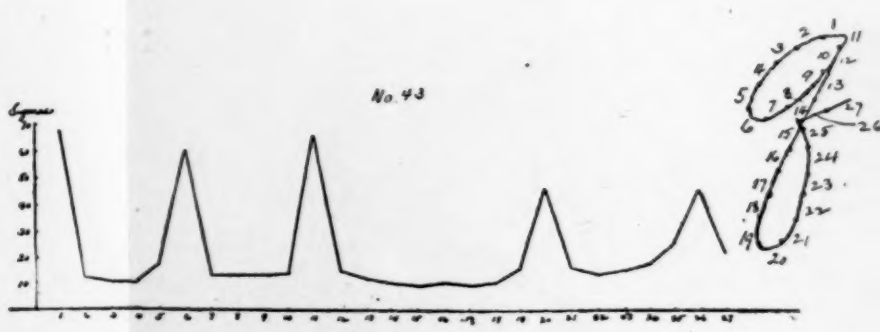
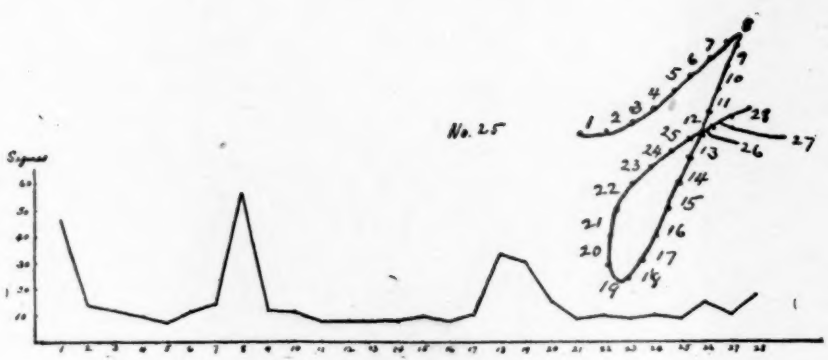
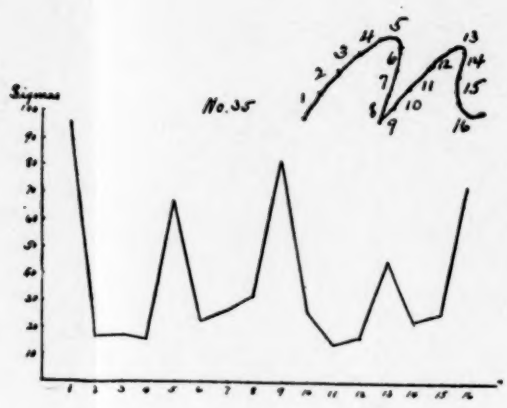
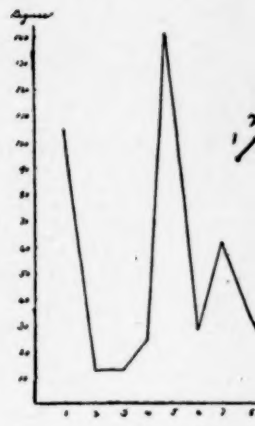
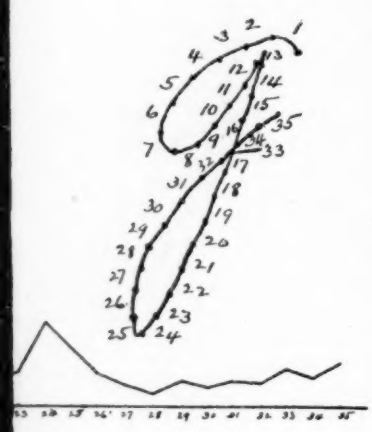


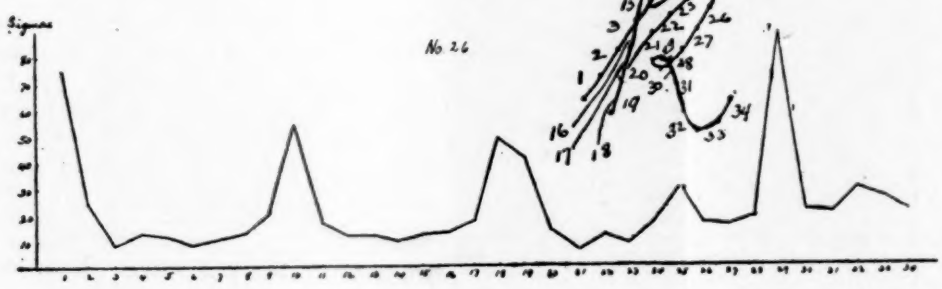
FIGURE 4—Reproducton of speed curves from all the letters of the alphabet from the writing of F. N. F.

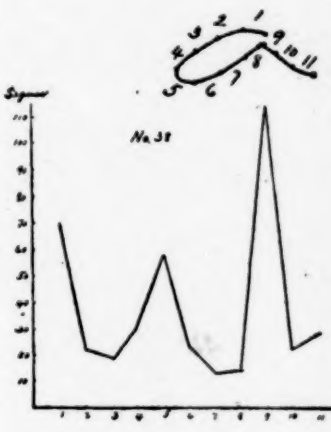


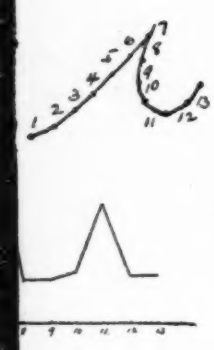


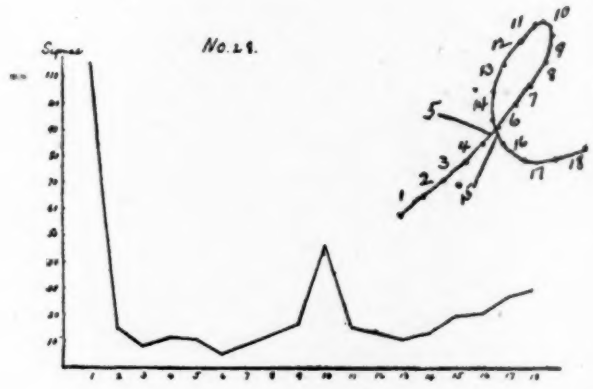


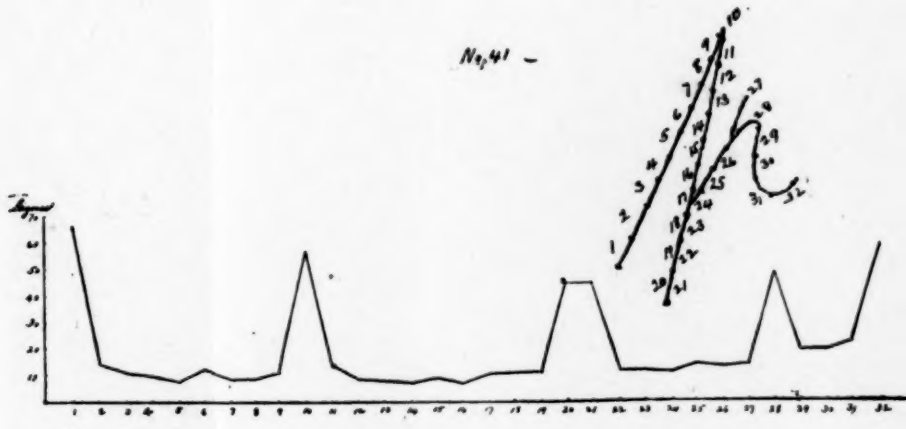


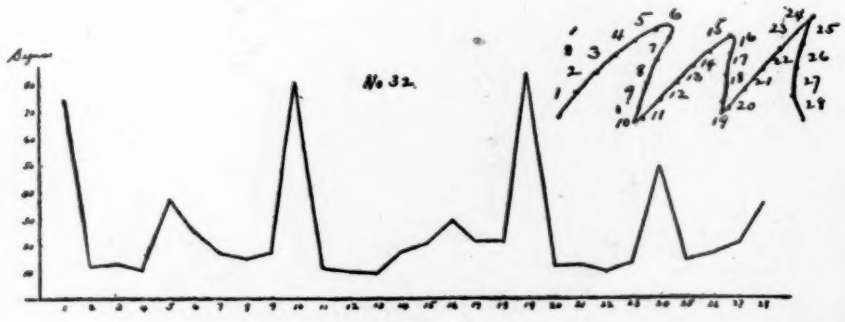












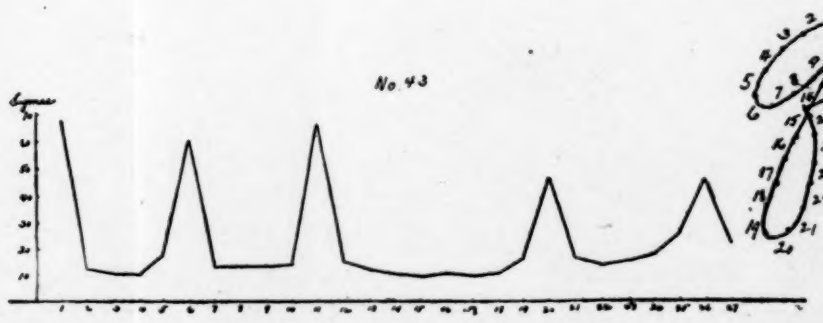
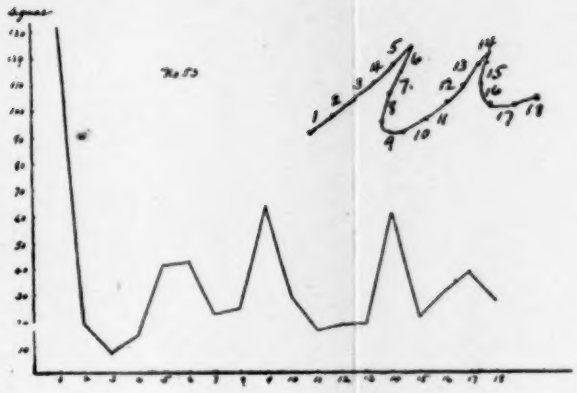


FIGURE 4—Reproducton of speed curves from all the letters of the alphabet from the writing of F. N. F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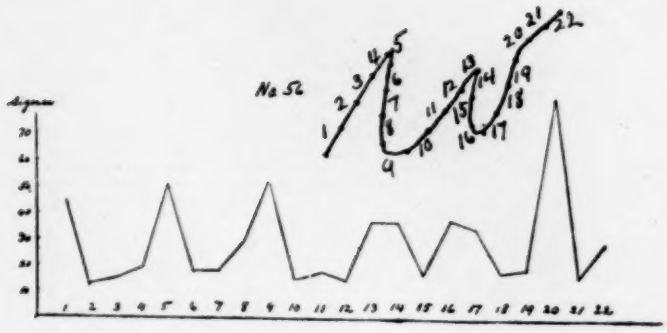
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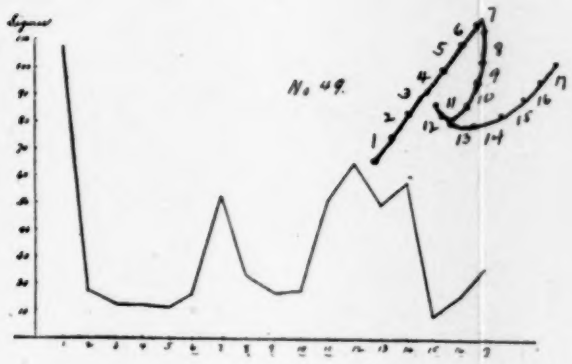
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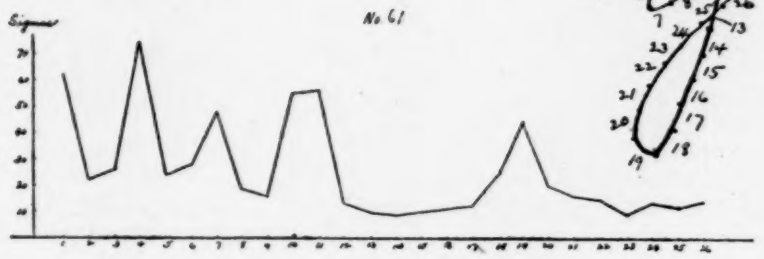
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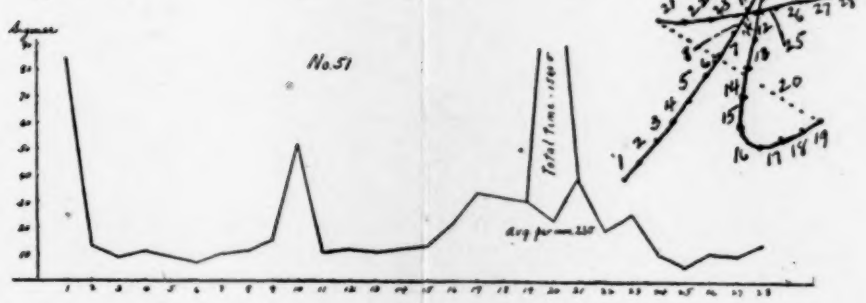
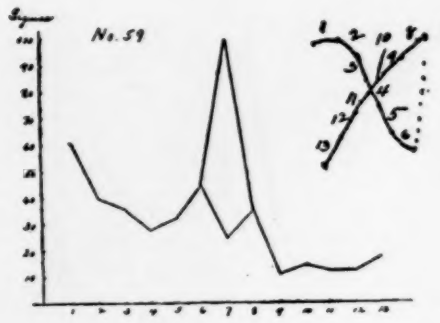

No 51
Total Time 1500
Avg per man 250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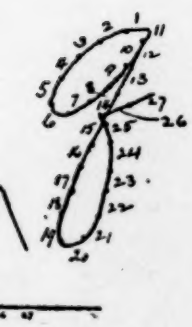

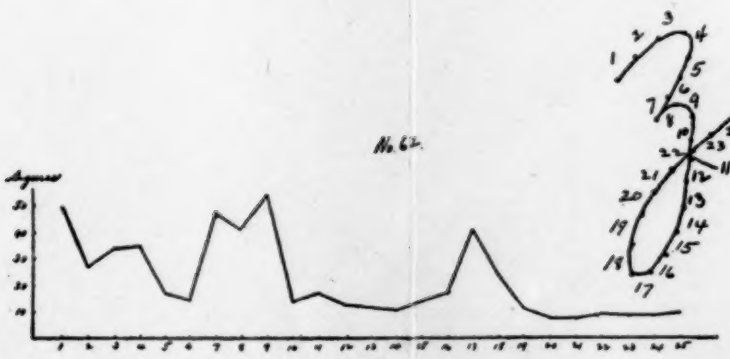
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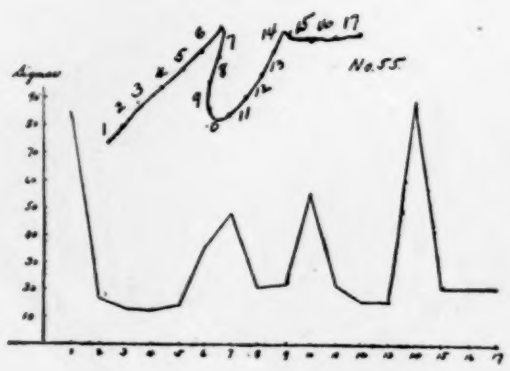
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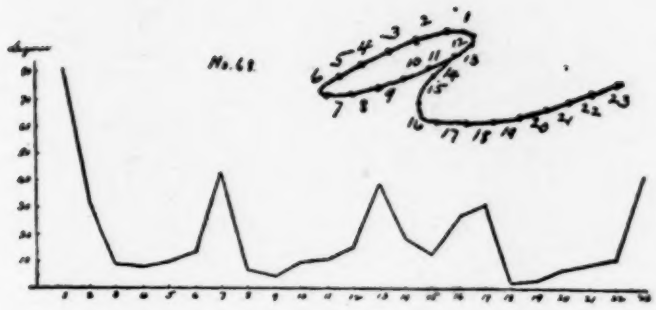
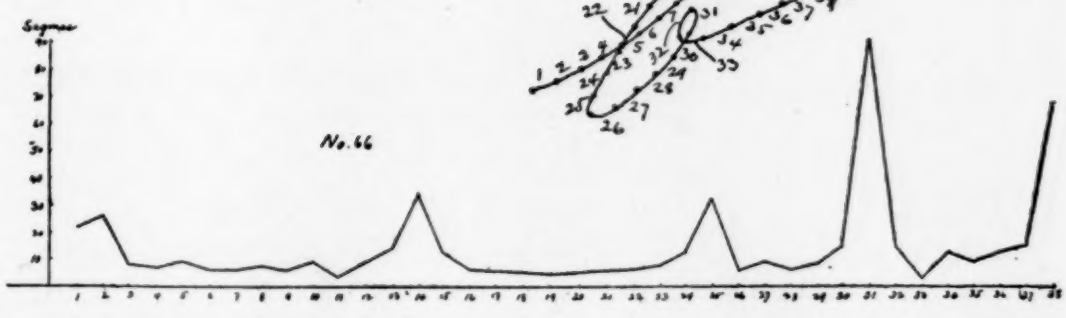
F. N. F.





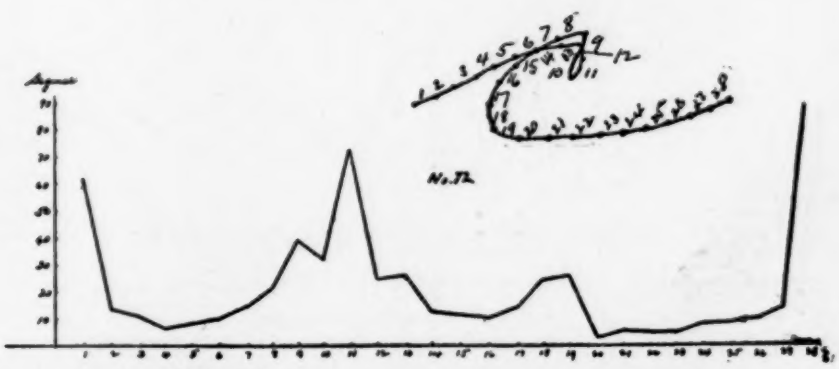


FIGURE 5—Reproduction of speed curves of letters written by T. T. G., D. H., and R. D. W.

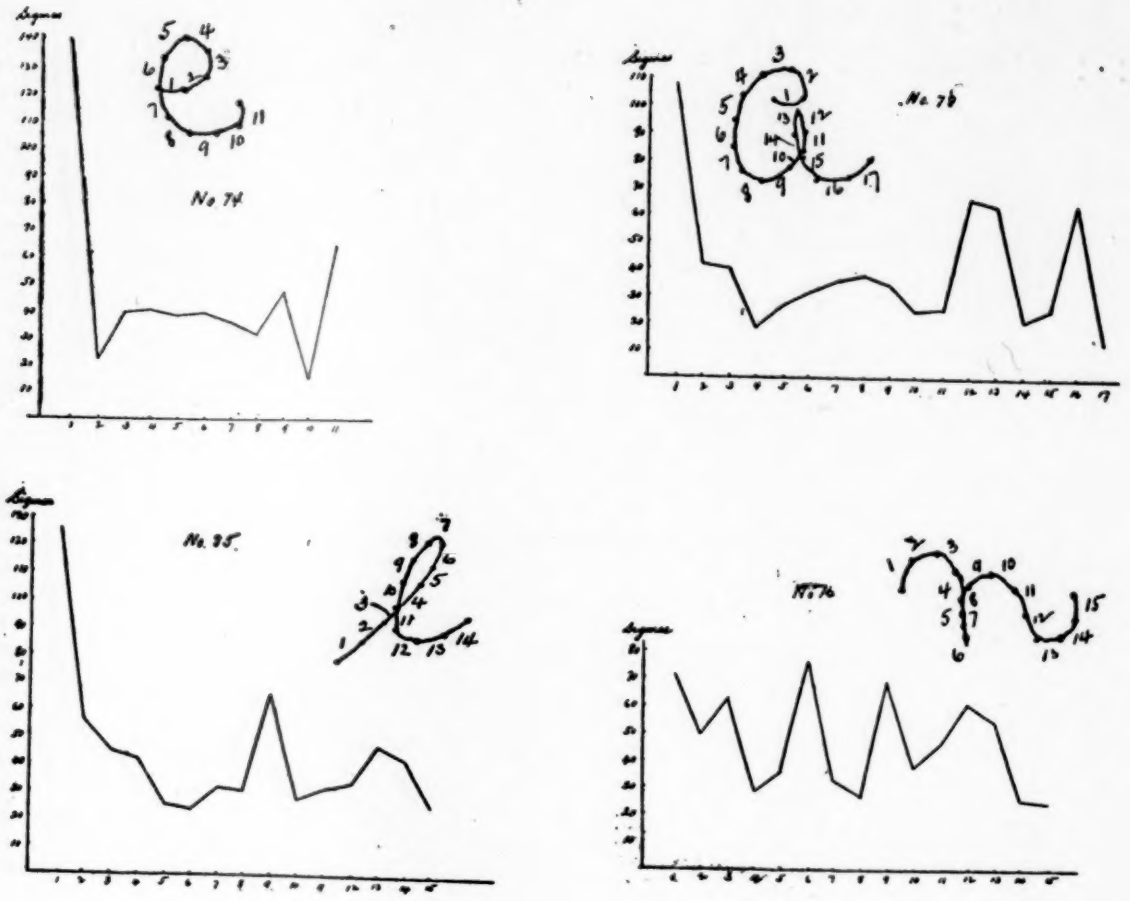


FIGURE 5 (Continued)

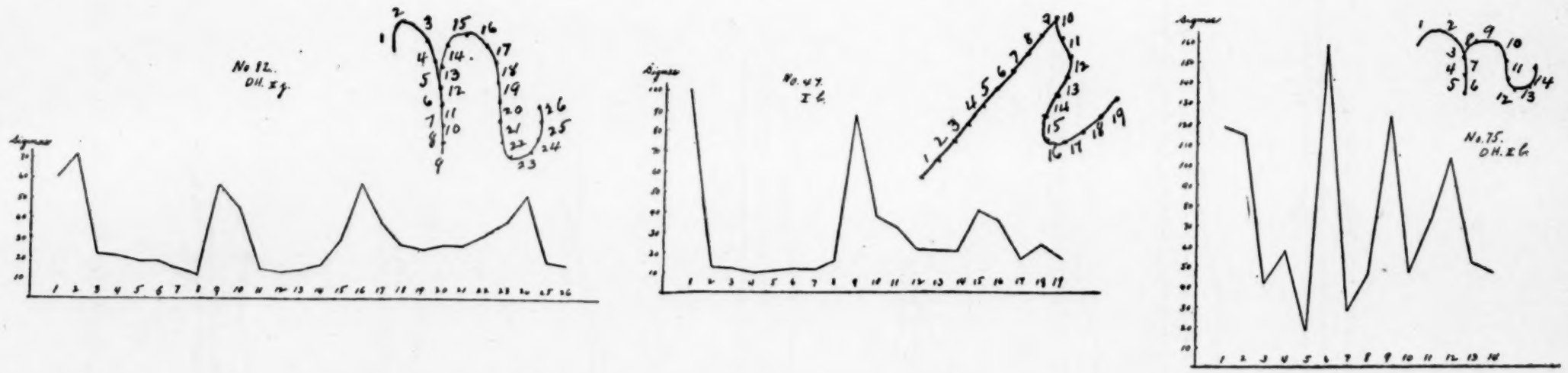


FIGURE 6—Reproduction of speed curves of letters written large by F. N. F. and D. H. (curves 47 and 82) and of a letter written between lines by D. H. (curve 75).

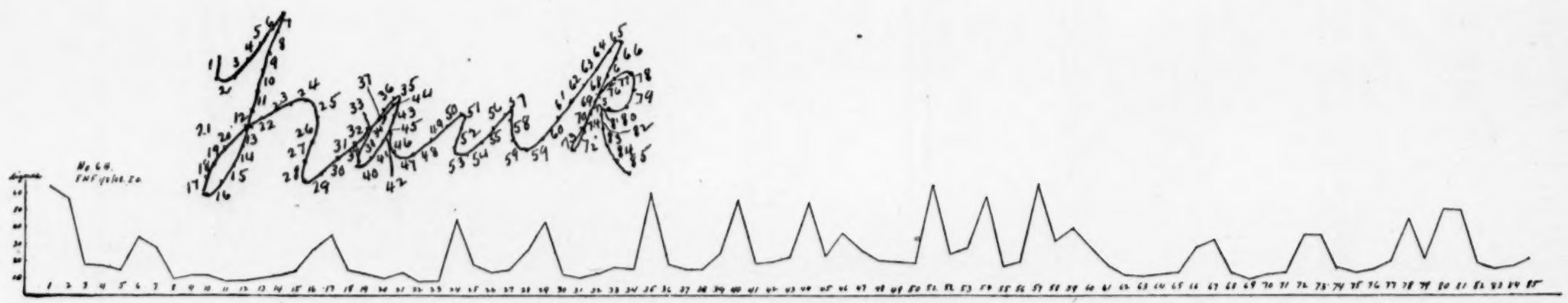


FIGURE 7—Speed curve of letters written connectedly in name by F. N. F.

Reactor F. N. F.

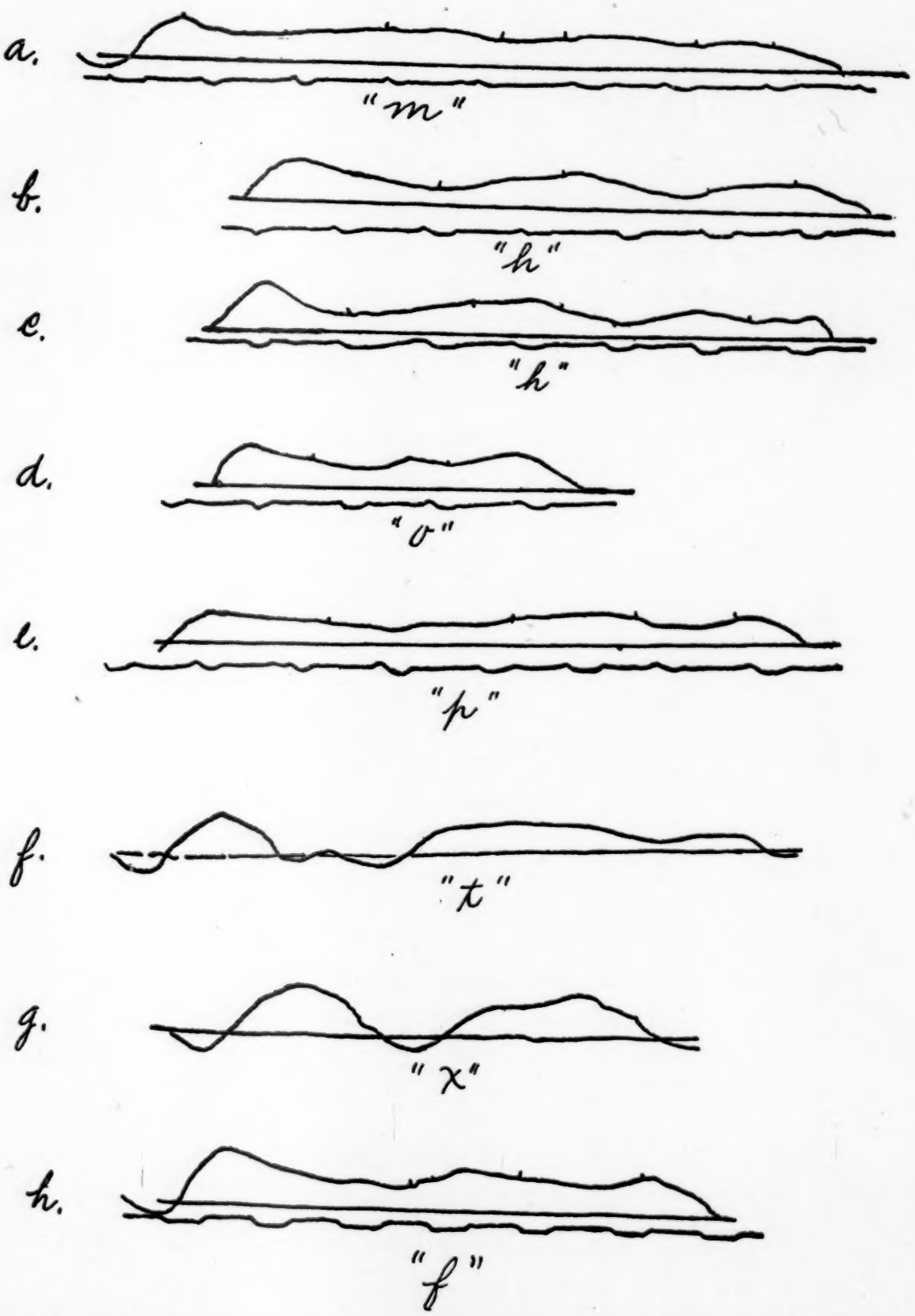
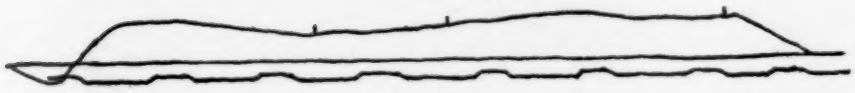
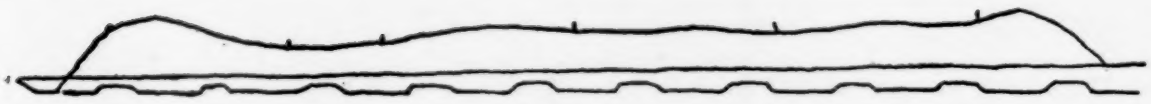


FIGURE 8—Pressure curves from the adult subjects, F. N. F., D. H., and R. D. W.

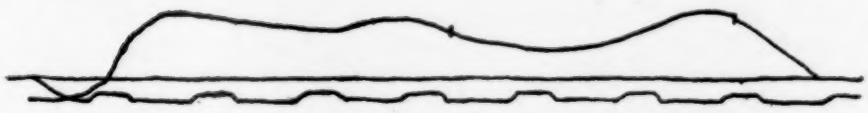
Reactor R D.W.



"e"

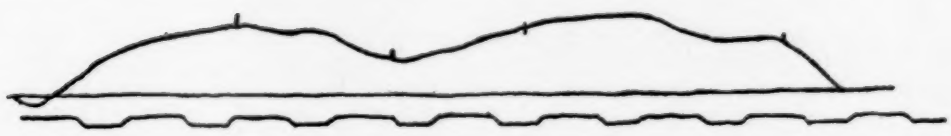


"m"

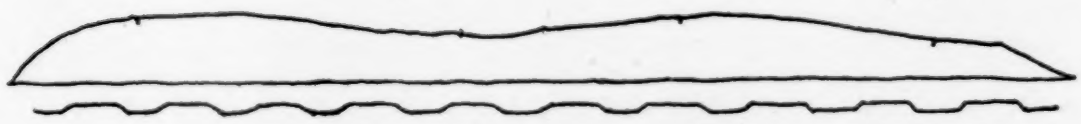


"r" (written large)

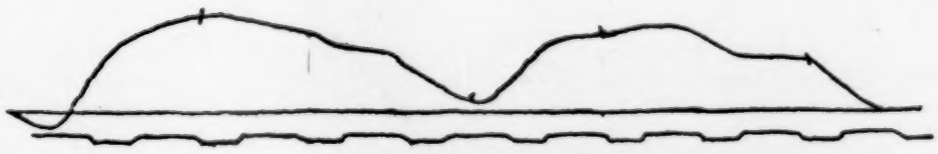
Reactor D.H



"n"

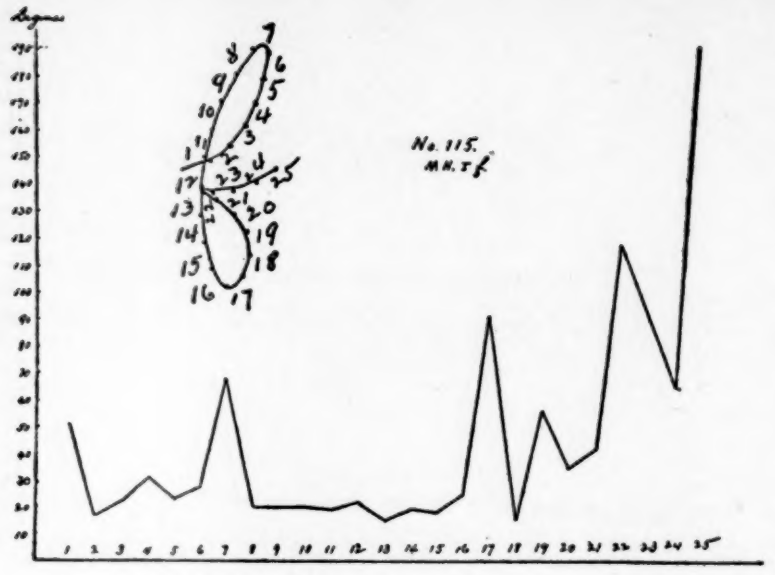


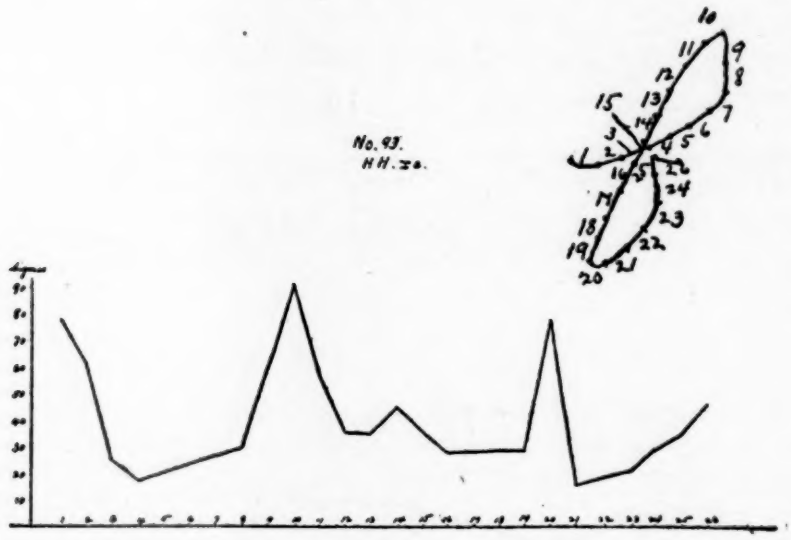
"n" (between lines)



"n" (written large)

FIGURE 8 (Continued)





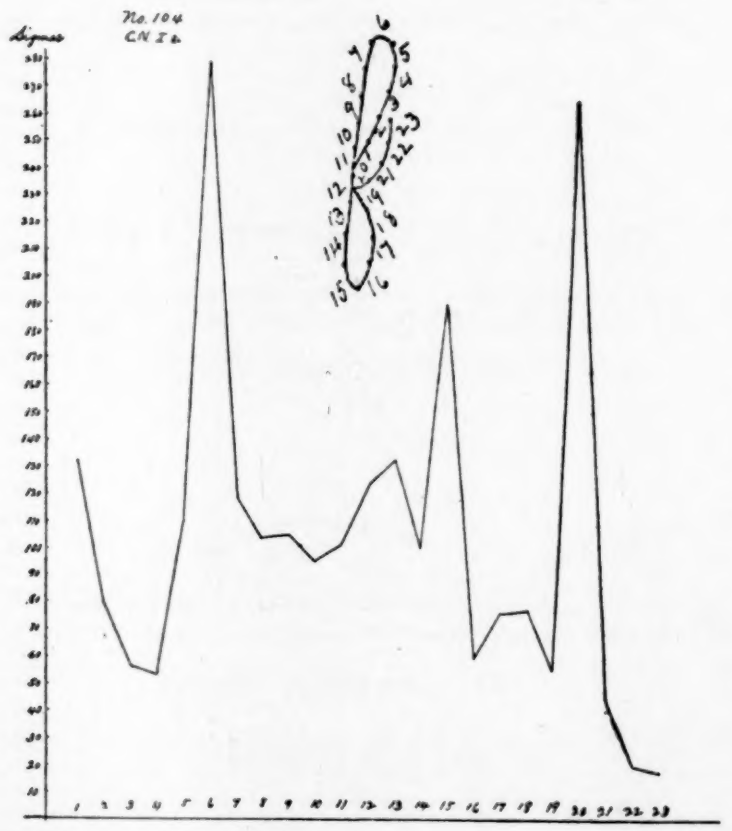
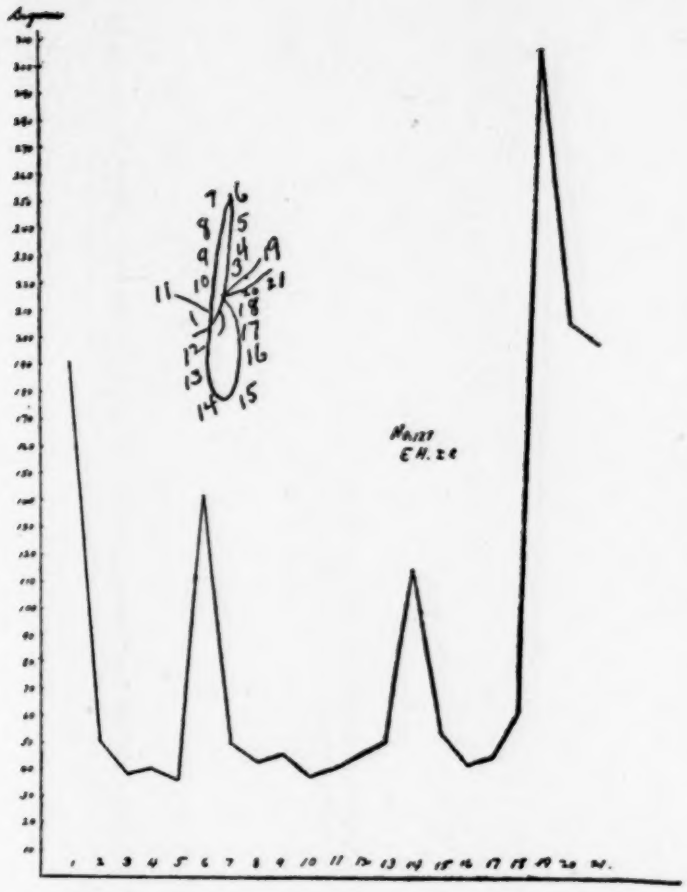


FIGURE 9—Speed curves of letters written by children, in usual manner



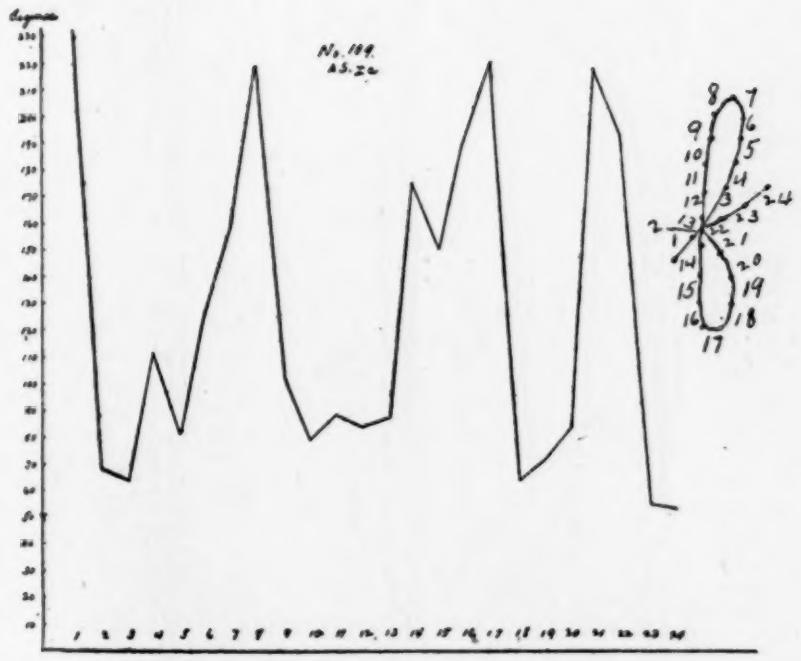


FIGURE 9 (Continued)—Speed curves of letters written by children in usual manner

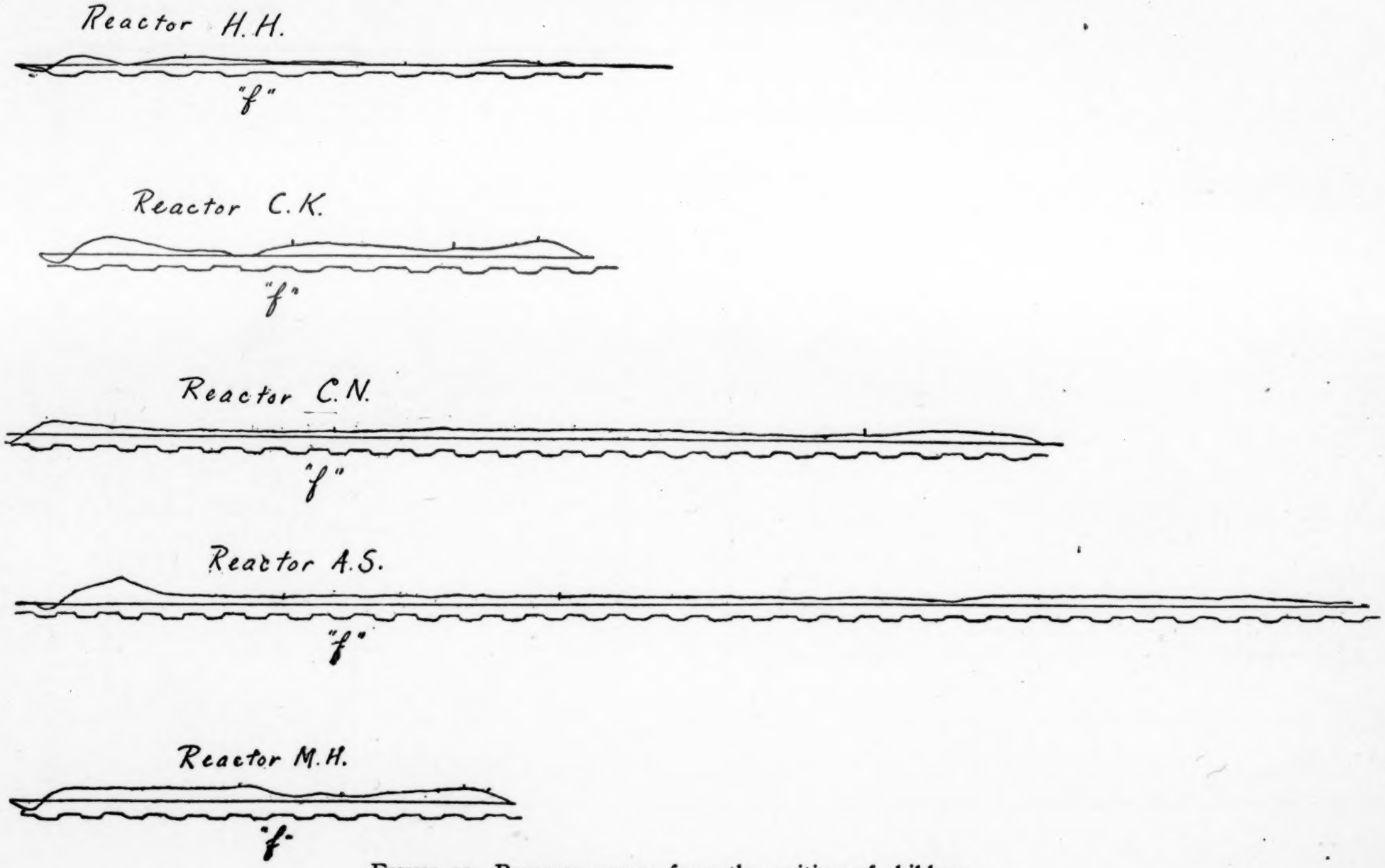
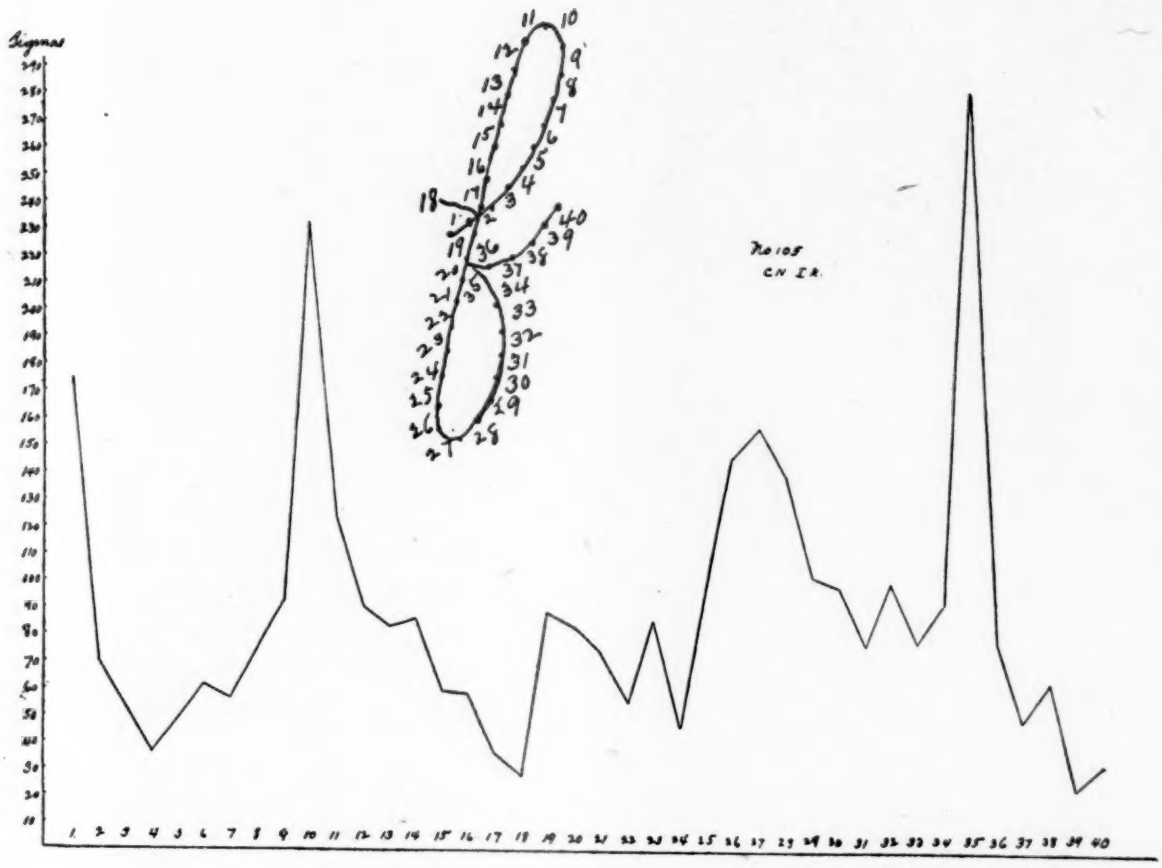
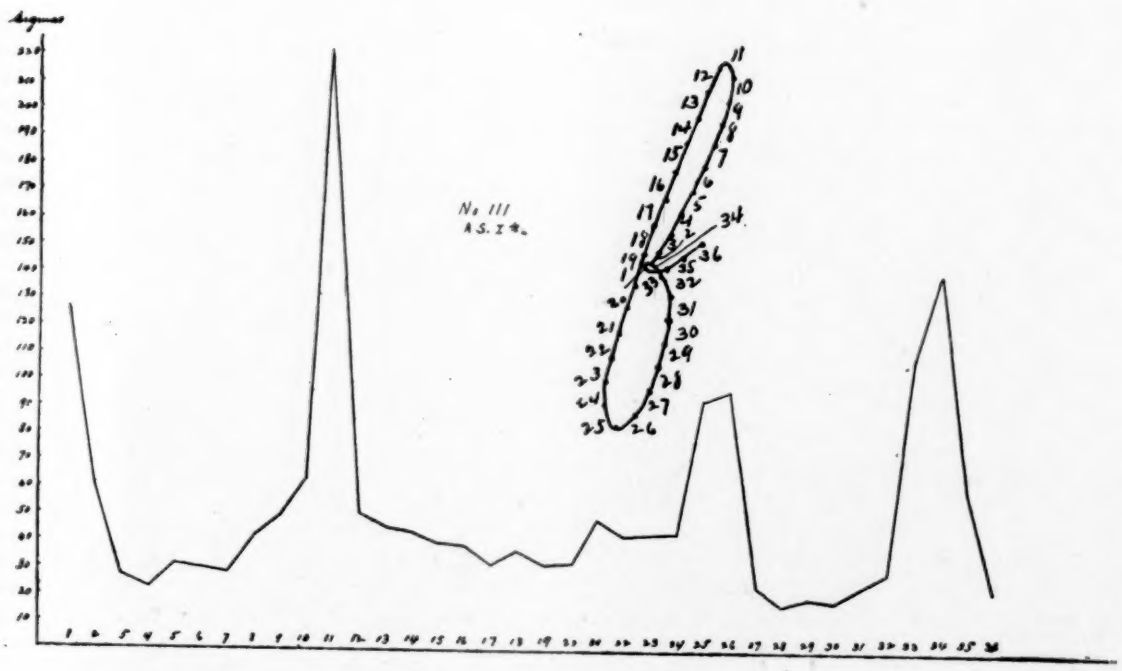


FIGURE 11—Pressure curves from the writing of children





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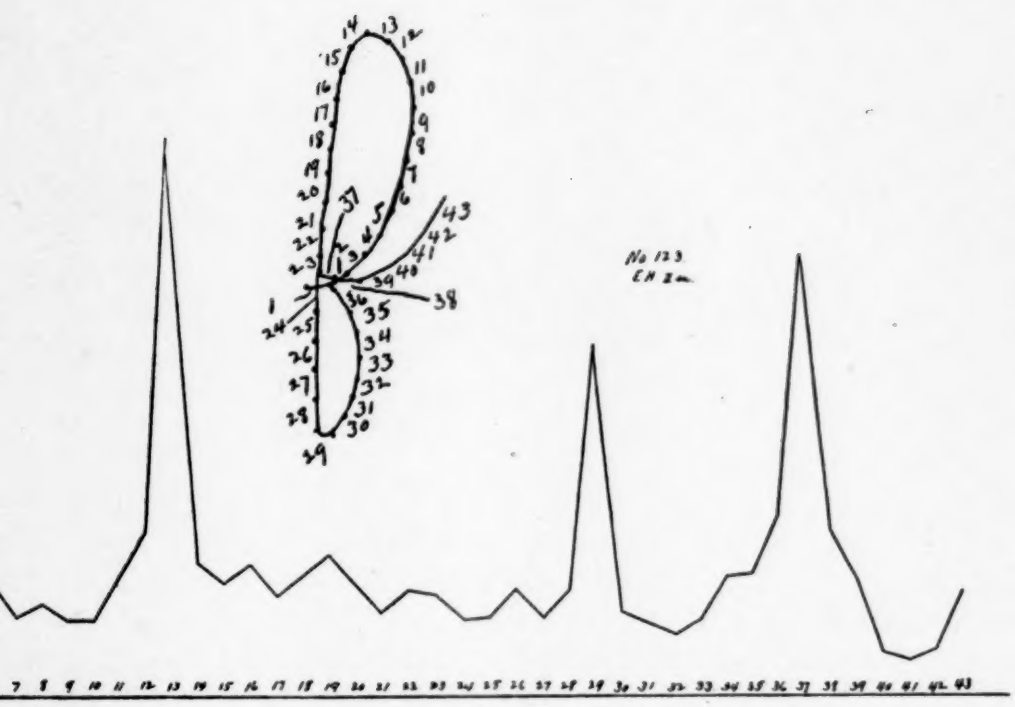
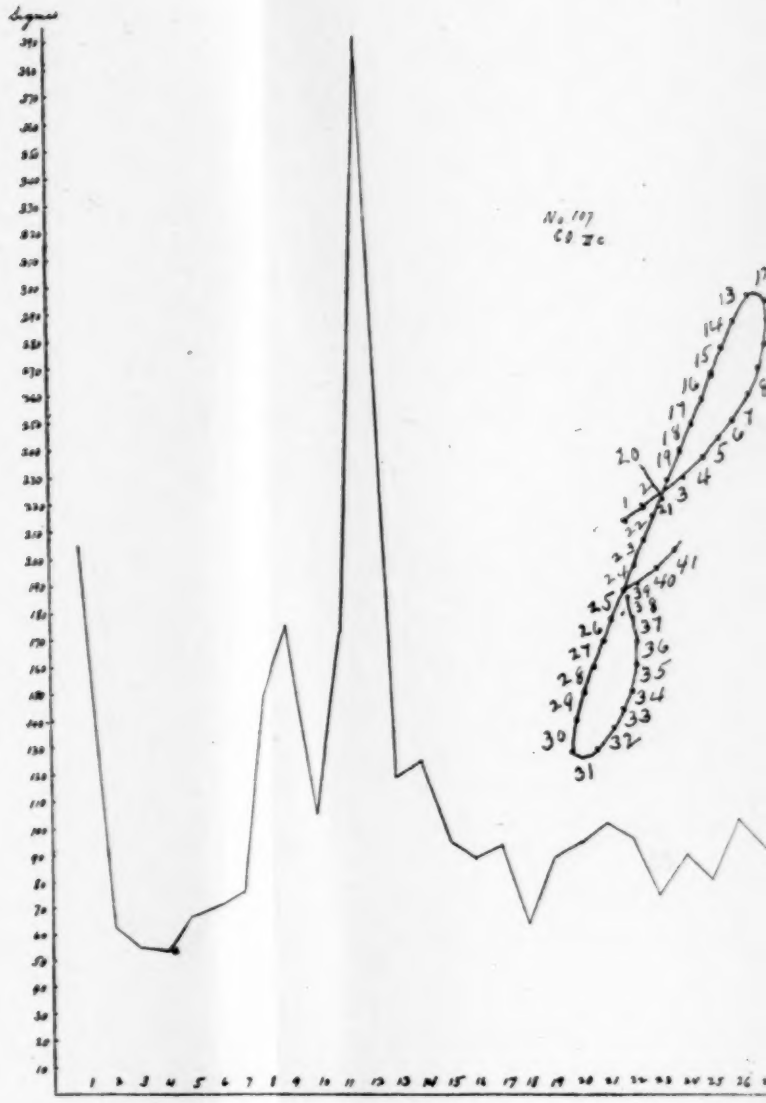
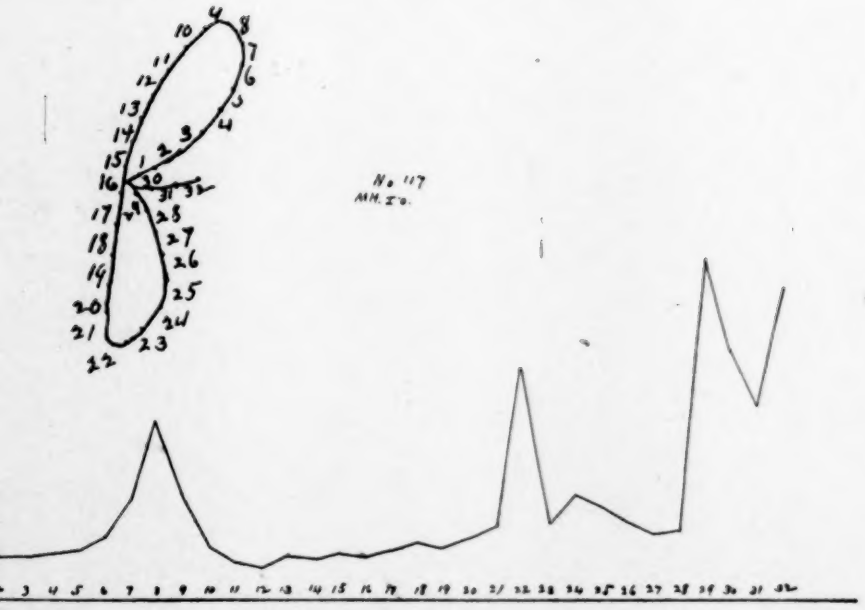






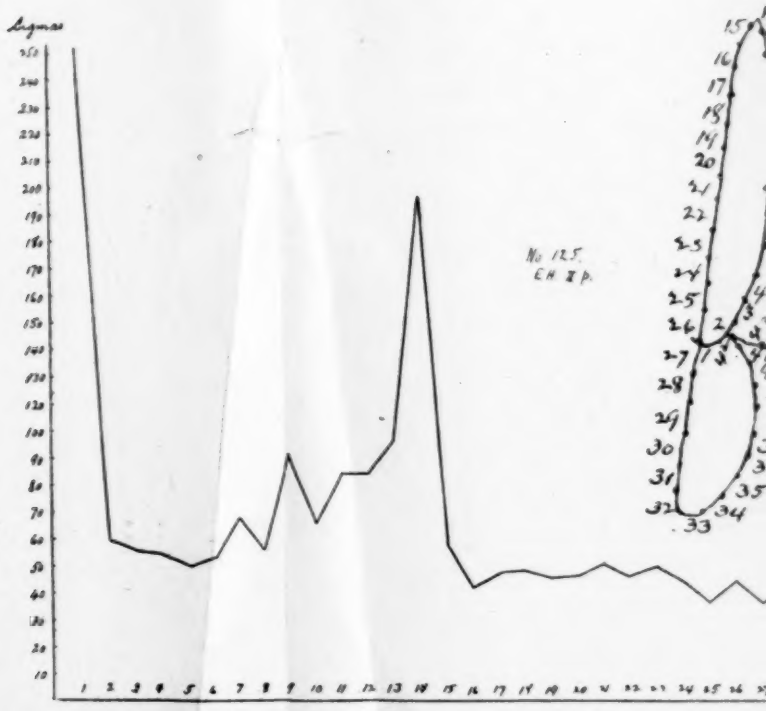
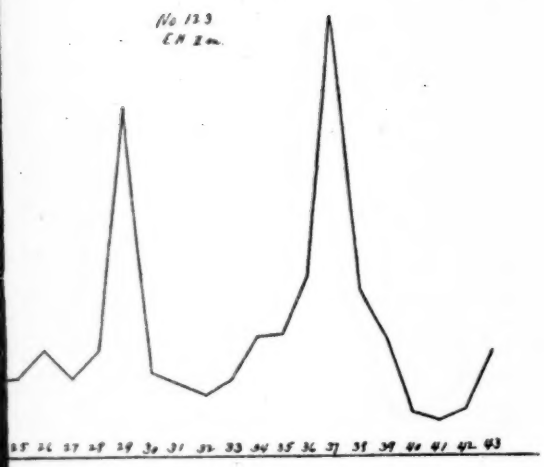
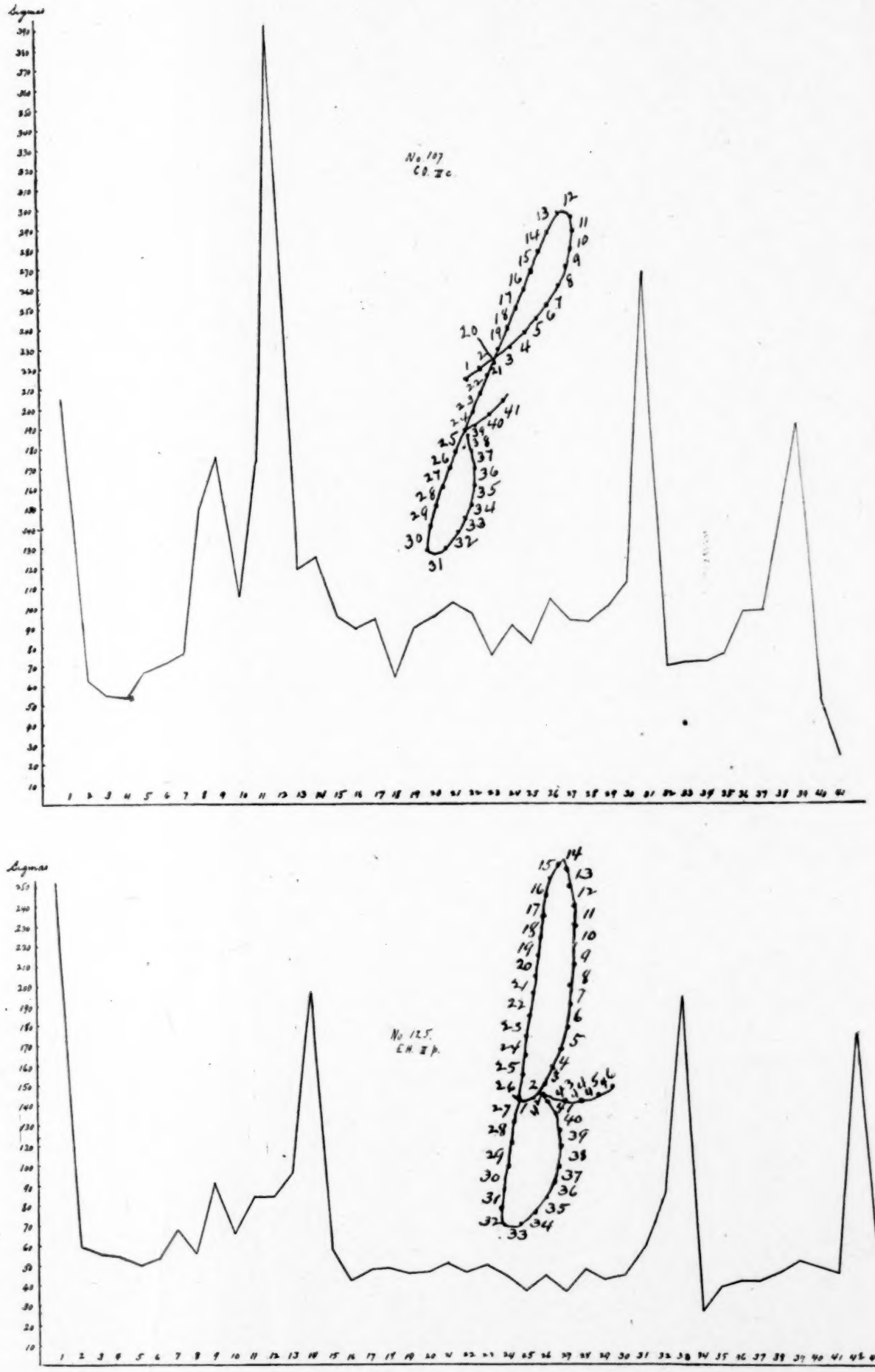
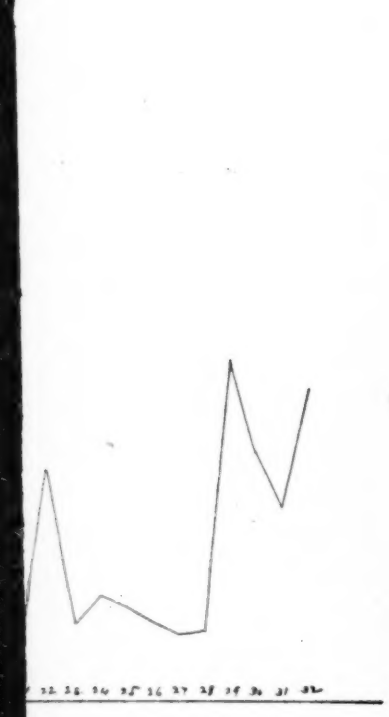


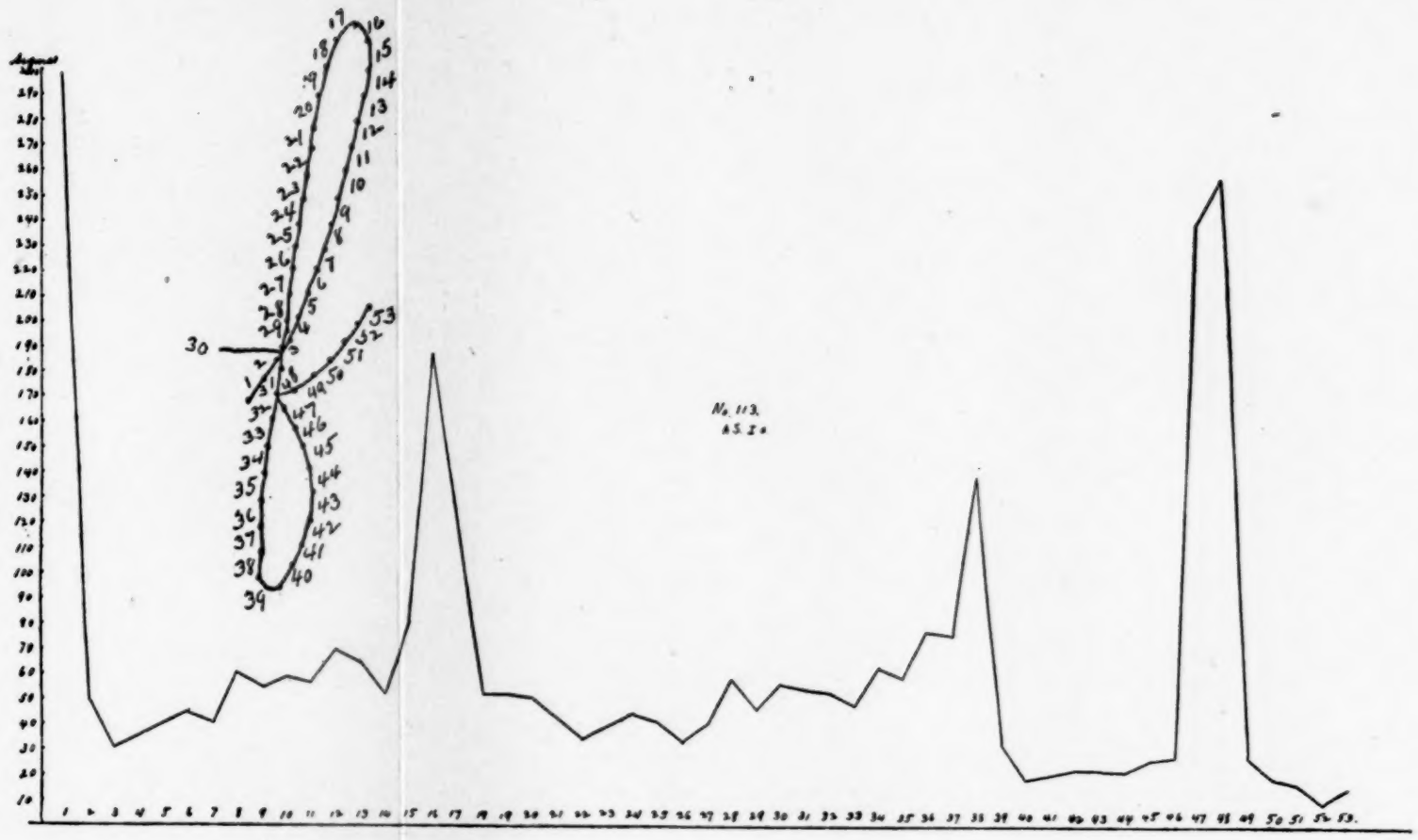
FIGURE 10—Speed curves of letters written by children, Nos. 105, 111, 123 and 117 written large, and Nos. 107, 125, 11

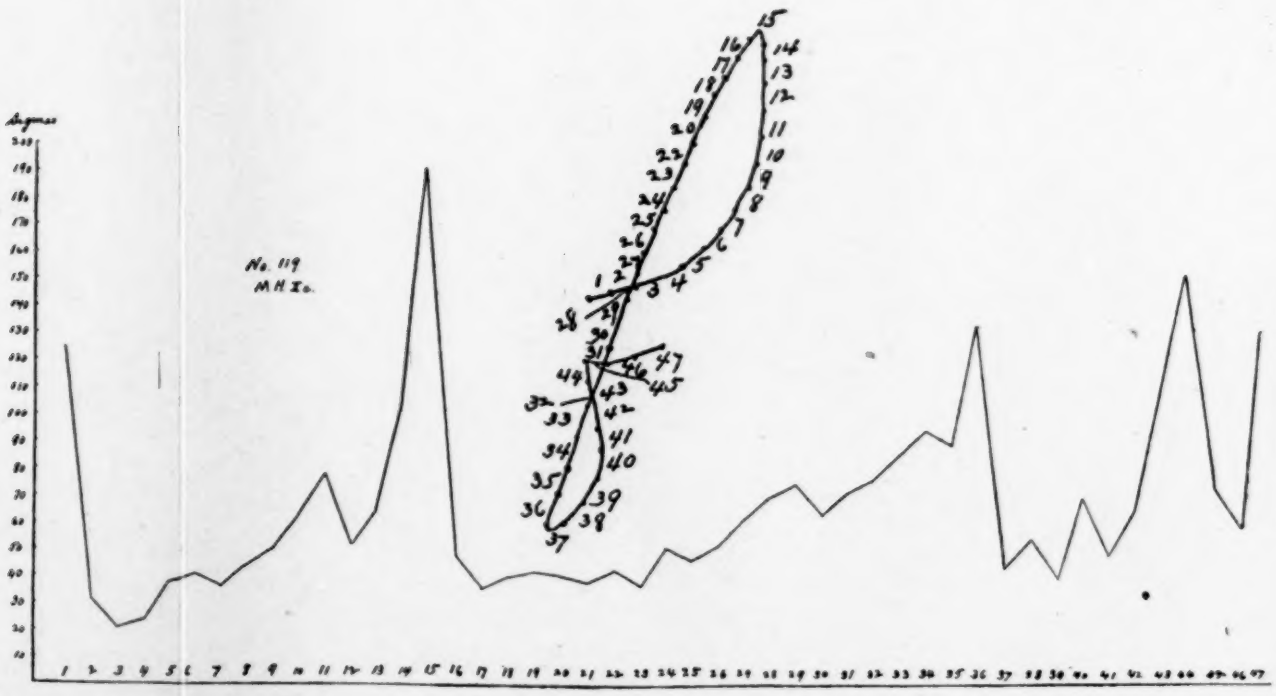






letters written by children, Nos. 105, 111, 123 and 117 written large, and Nos. 107, 125, 113 and 119 written between lines





en lines

EXPERIMENTAL ANALYSIS OF FORMS OF REACTION MOVEMENT[1]

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The apparatus was designed to record not only reaction times but the total form of each reaction movement as well, i.e., the speed and pressure variations from before the warning signal to the end of the reaction movement. The purpose of the whole investigation was, therefore, to study the correlations between reaction time, form of movement and introspective consciousness, particularly the direction of attention. The analysis of the conditions determining "antagonistic reactions" was specially emphasized.

The results show, in general, definite and fairly constant correlation between variations in reaction time, reaction form, and the direction of the attention. Specifically, in the typical "motor" reaction there occurred, along with shorter times and the direction of the attention to the movement to be made, a gradual decrease in the pressure of the finger on the reaction key from the warning signal to the beginning of the final reaction to the stimulus, this final movement being a simple sharp rise of the finger from the key. In the typical "sensory" reaction there occurred, along with the longer times and the direction of the attention to the stimulus, a uniform or increased pressure from the warning signal on, terminating in a final reaction movement of antagonistic form in response to the stimulus, i.e., a downward pressure of the finger before it was lifted from the key. The average correction in the reaction movement made necessary by this antagonistic phase was 30 σ.

Types of reactors also appeared, the differences in type involving the reaction time, the attention and the form of reaction movement.

I. HISTORICAL

The investigation here reported was essentially an experimental study of *forms* of reaction movements graphically recorded. In particular, the aim was to discover what correlations, if any, arise in practice series between reaction form and reaction time, or between form and the direction of attention. Since the

[1] A condensation of a thesis submitted in partial fulfilment of the requirements of the degree of Doctor of Philosophy in Yale University, in May, 1909.

so-called antagonistic reaction is intimately involved in these questions special study was given to it.

The importance of the study of forms of reaction movements as distinguished from the mere investigation of reaction times and their introspective accompaniments was first brought prominently to light by Smith (**5**) in 1903. He had noticed in earlier reaction work that a reactor, in responding to the stimulus, does not always lift his finger immediately from the key on hearing the stimulus, but often presses down before making the final upward movement. This type of reaction Smith called "antagonistic reaction movement."

In order to obtain graphic records of such a movement, Smith used a piece of stiff rubber tubing. Making one end air tight he connected the other with a recording tambour by a rubber tube. The reactor placed his finger on the stiff tubing and reacted by lifting the finger. The form of the reaction movement was thus recorded on the smoked paper of a kymograph. By means of a time line from a 100 v.d. tuning fork the time between the giving of the stimulus and the beginning of *any* movement, as well as that between the giving of the stimulus and the beginning of the *final upward* movement could be determined, the difference between them showing the time added to the reaction by the antagonistic movement.

Smith reports the results from 33 subjects, 25 men and 8 women. Of these subjects he found 5 fairly constant antagonistic reactors, while 5 were intermittent in this type of reaction. Eighteen of the subjects gave no sign of the antagonistic movement. The remaining 5 were difficult of interpretation.

The average reaction time, i.e., to the beginning of the final upward movement, for sensory reactions for 3 antagonistic subjects was 200σ, 170σ, and 180σ, respectively. Corrected to the beginning of movement, these same subjects gave 180σ, 140σ, and 140σ. The antagonistic portions of the reactions were, therefore, 20σ, 30σ, and 40σ. One result of this investigation was, certainly, to show the obvious value of the study of the form of movement in reaction experiments, and this can be done only by the graphic method of recording. The importance

of this general result is emphasized by a further fact, namely, that the form of reaction may change during the course of an experiment, for Smith found that the antagonistic reaction does not always appear at the beginning of the series. It may not appear until several series have been taken.

Smith then carried on some extended experiments in order to determine the cause of the antagonistic reaction. He tried first the sensorial-muscular distinction in attention. He found that the antagonistic movement occurred in both forms of reaction, but that it was more frequent in the motor type. Experiments on the influence of distraction and fatigue on the antagonistic reaction gave no univocal results. Reactions were also taken with different sets of muscles, with different positions of the arm, and with different fingers. The antagonistic reaction movement remained under all conditions. Smith says (p. 57): "In every direction of movement, up or down, to the right or left, there were observed preliminary movements in the direction opposite to that intended by the reagent. The movements are not equal in both cases, but the curves of both persons experimented upon show the phenomenon unmistakably." It was not due, then, to any special set of muscles or to any position of those muscles.

Smith presents an explanation for the antagonistic movement both from the physiological and from the psychophysical standpoints. Physiologically, he bases his explanation on the now well known work of Sherrington, in which it is shown "that when one of the pair of antagonistic muscles is innervated, there is a simultaneous inhibition of the muscles opposed to it." With this cue, Smith reasons that the muscles already innervated would tend to persist in their activity after the stimulus and before the subsequent inhibition occurs. From the psychophysical standpoint he states that in the period preceding the occurrence of the stimulus the most prominent idea in the mind of the reactor is that of holding the finger down on the key. The stimulus comes as a kind of shock. This shock tends, he thinks, to emphasize the idea already in consciousness in the instant preceding the voluntary decision to lift the finger. He mentions cer-

tain cases of patients suffering from general paralysis in which he has noticed this preliminary tightening of the muscles before the final action.

Smith suggests a number of problems for future work, largely along the line of a more definite training of the subjects under different experimental conditions, particularly those of attention.

Other references to Smith's antagonistic reaction which I have been able to find outside the work on reaction movements done in the Yale laboratory are by Titchener (**6**, 352-355) and by Franz (**2**). Titchener, reviewing Smith's work and that of the Yale laboratory, suggests further problems which need to be worked out in connection with the antagonistic movement, e.g., the effects of practice, of definite instruction, of introspective control. He favors *a priori* the view that the antagonistic form of reaction will appear more often in the motor reactions, and states that he has tried some experiments with the press reaction, but that no antagonistic movement was found. The experiments were, however, so few in number that no general conclusions can be drawn from them. Franz found that the reaction times of a depressed or retarded patient were longer than the normal and, much to his surprise, that simple reaction times increased without any change in choice reaction times. This change was so marked that in certain series the choice reactions were shorter than the simple. Since there was no evidence that the subject had changed the character of his attention in the simple reactions, or that fatigue played any part, Franz believed that he might be dealing with the antagonistic reaction movement. Smith had already stated that he had noted preliminary contractions in partially paralytic patients. Franz made no attempt in his investigation to determine this point.

In 1905 Judd, McAllister and Steele (**3**) published an investigation on the character of reaction movements. Graphic records of both simple and discrimination reactions were taken from 51 subjects—a total of 964 records of simple reactions and 523 of discrimination reactions. A special apparatus was constructed, consisting of a reaction key attached to one end of a metal spring in such a way that when the spring was depressed

the reaction circuit was made; when the spring was released the circuit was broken (pp. 143, 144). A lever attached to the spring near the key recorded every change in pressure directly on a long strip of smoked paper. Times were taken with a Hipp chronoscope.

These authors were interested not only in the nature of the reaction movement subsequent to the giving of the stimulus and terminating in a lifting of the finger, but also in the movements made in the period between the warning signal and the stimulus. They show drawings of many forms of movement, all more or less complicated, which lead to the conclusion that there is "no such thing as a simple reaction movement." All these records show, too, complex forms of adjustment in the period before the stimulus which determine the character of the final movement. For purposes of analysis the total reaction period was divided into that before the warning, that immediately following the warning, that just before the stimulus, and the final movement. An analysis of all the records yields three main types of reaction (pp. 166, 167):

1. "The balanced type," a balancing of the antagonistic muscles shown by waves in the record.

2. "The antagonistic type," in which the pressure gradually increases in the period before the stimulus or suddenly increases directly after the stimulus.

3. "The partial reaction type," in which the tendency to react overpowers the antagonistic tendency, resulting in a partial reaction before the stimulus.

The authors believe, therefore, that their results support the theory of reaction types, if by types is meant "individual tendencies even in untrained subjects to adopt a particular mode of reaction" (p. 179). The form of reaction was found to change, however, with a change in the "character of the task required" (p. 173) and it was clear that introspective evidence of the character of movement was not to be relied on (p. 180).

Concerning the relation between form of movement and reaction time (pp. 169 ff.), it was found that a gradual antagonistic pressure in the period preceding the stimulus was advantageous

for quick reaction. The sudden antagonistic reactions were, however, cases of excessive effort which, properly applied, meant speed but often, improperly applied, interfered with speed. The sudden antagonistic movement did not, therefore, as regularly promote speed as did the gradual. So far as the relation between form of movement and consciousness is concerned, the gradual increase in pressure "would indicate a growing emphasis in consciousness of the necessity of holding the hand down until the stimulus arrived" (p. 181), while the sudden antagonistic movement at the end seemed to be a matter of nerve mechanism rather than the result of a conscious process (p. 182).

Finally, as problems for future work, are suggested the training of subjects in a "particular mode of reaction" and the study of the development of habits of movement (p. 177).

II. APPARATUS AND METHOD

The present investigation takes up the study of the form of reaction movements where the authors last mentioned left it and has, in general, a fourfold purpose: following their suggestions, five untrained subjects were, without special instructions, carried through a long series of reactions to see, first, if they would develop definite forms of movement; second, if during such a practice series a change in the form of movement would accompany the reduction of the reaction times and mean variations. The results of two of these reactors, reported in the original thesis, are omitted for lack of space. They agree with the results of the three reactors here reported. Five other subjects were trained to keep their attention on the stimulus or on the movement to see, third, if any differences in the form of the reaction movement accompanied the differences in the direction of the attention. The results of two of these subjects are omitted because of the small number of reactions that could be obtained from them. In their few series there appeared no differences in the form of reaction movement correlative to the differences in the direction of the attention. In all, then, the work of six subjects is reported in this article. Fourthly, special

attention was paid throughout the investigation to the antagonistic form of reaction first described by Smith (**5**), in order to determine if possible the conditions that occasion it.

Graphic records were taken of all the reactions. The form of reaction apparatus was the same as that used by Judd, McAllister and Steele (**3**), a full description of which, together with a discussion of its possibilities and advantages, will be found in their article (pp. 143-145).

Some modifications in the method of recording the changes in pressure were, however, introduced. Fig. 1 shows these in side

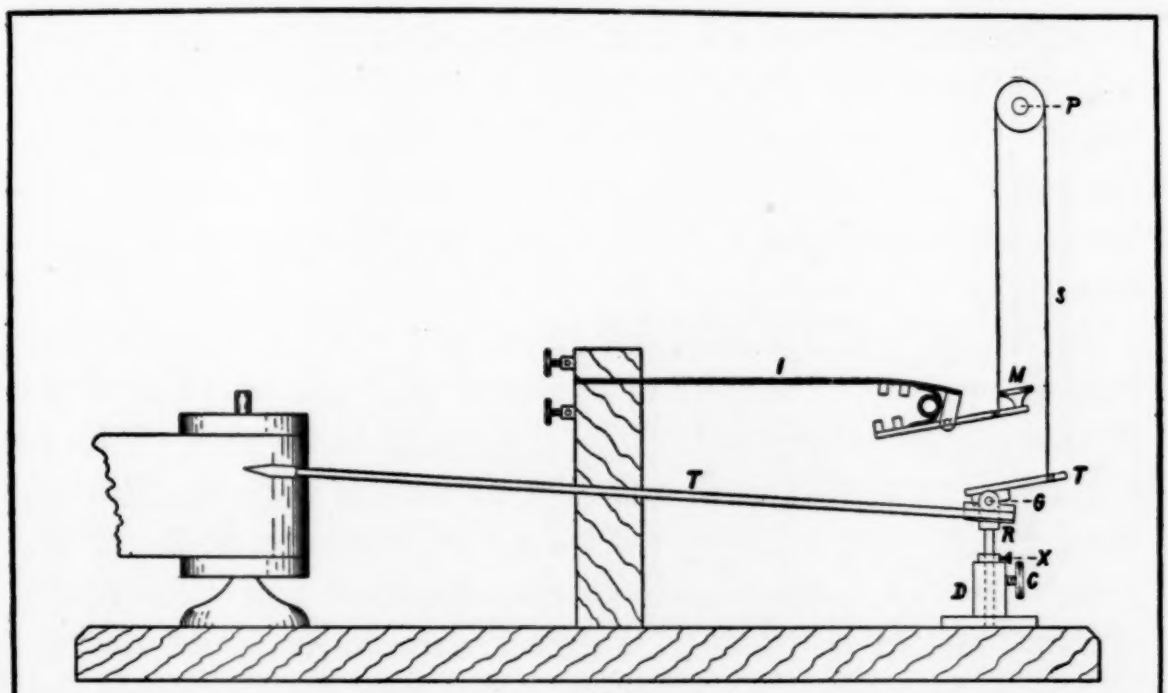


Fig. 1.

view. A thread, S, was fastened to the reaction key, M, carried up over a small pully wheel, P, and down to the end of a light bamboo rod, 12 cm. long. This rod, T′, was securely fastened to a brass rod, G, which passed through a hole in the brass block, R. On the other end of the rod, G, was attached a bamboo rod, 36 cm. long, T, which extended to the vertical recording drum and carried at its extremity a steel point which registered the changes in pressure on the smoked paper. These two rods, T and T′, thus formed an enlarging lever by means of which the changes in pressure on the key, M, and spring, I, were recorded directly, enlarged three times, on the moving paper. Because of

the thread and pulley, there was no reversal of movement as was the case with the simple lever used in the earlier form of the apparatus. The brass block, R, was mounted on a rod which could be raised or lowered in the metal base, D, by means of the collar, X. By means of the screw, C, the amount of pressure of the pointer upon the paper could be regulated. This screw also permitted the pointer to be drawn back slightly from the paper to allow smoking and shellacking.

The records made with this form of apparatus differ materially from those taken with the earlier form, as well as from those of Smith, taken with a tambour. The advantage of the lever record over the tambour record is that with the lever the length of movement recorded corresponds directly to the amount of movement made. The advantage of this particular type of lever record over the earlier type is that, since the movement is not reversed, the form of movement can be more readily interpreted from the form of the curve.

As in the earlier work, strips of smoked paper about fifty feet long were used. The method of shellacking was also the same. It seemed best, however, to have the paper move at a uniform rate so that the changes in muscular movement occurring during the reaction could be compared by simple inspection of the curve rather than by constant reference to the time line. To attain uniform rate of movement the drums were driven by an electric motor. The motor was attached to the drum farthest from the reaction key and the proper speed was obtained by means of direct reduction through a worm gear. To do away as much as possible with the noise connected with such an arrangement, the motor was mounted on several thicknesses of rubber matting, then wrapped in many layers of thick cloth and placed in the center of a large box. This box was filled to the top with cotton waste and the whole securely covered. The residual noise of the motor, although slight, undoubtedly had, however, some distracting effect. This appeared most at the beginning of each series. Such a distraction was overcome in part by having the subject react a few times before the recorded series was begun. To any remaining distraction from the motor the subject doubt-

less became so well adapted that it could be considered a constant in the experiment. This was indicated by some later experiments in which the drums were turned by hand. The reactor was so much distracted by the lack of noise that it became necessary to start the motor whether it was used to turn the drums or not.

Figs. 2 and 3 show in diagrammatic form the entire apparatus and the wiring. The reaction circuit is shown in Fig. 2. The

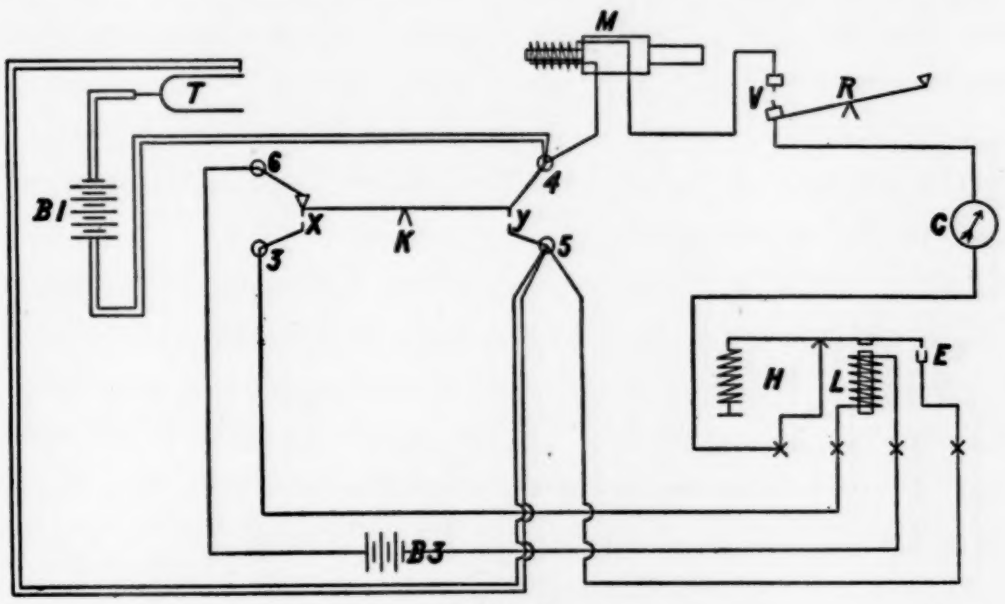


Fig. 2.

Apparatus and Connections of a Reaction Circuit.

current passes from battery B1, through the 100 v.d. Koenig fork, T, to one of the break poles, 5, of the make and break key, K. In the normal position of the key the current passes across the contact, Y, to the post, 4, and so back to the battery, B1. This circuit keeps the fork in constant vibration when it is not in use in the reaction circuit. If the contact is broken at Y in the key, K, the current then passes from the battery, B1, through the fork, T, to post 5 of key K. Being unable to cross at Y, it takes the longer circuit to the electric hammer, H, through which it passes when the contact, E, is made. From the hammer the current passes through the Ewald chronoscope, C, to the reaction key, R. At R it crosses the contact, V, when

this contact is made by the reactor, to the marker, M, and back to post 4, from which point it returns to the battery, B1.

The same movement which breaks the contact, Y, on key K, makes an instant later the contact at X. This allows the current from battery, B3, to pass from the make pole, 6, across X to the make pole, 3, through the magnets, L, of the electric hammer, H, and back to the battery, B3. When L becomes a magnet, the hammer is pulled down, giving the sound for the stimulus and completing the reaction circuit at E. The pressing of key K, then, gives the stimulus for the reaction and also completes the reaction circuit, starting the chronoscope and marker. Upon hearing the stimulus the reactor breaks the circuit at V, stopping the chronoscope and marker, after which the operator releases the key, K, allowing the fork to be run once more by means of the shorter circuit.

The tracing of a continuous time line, a procedure employed by Judd, McAllister and Steele, was not entirely satisfactory, since the marker fastened to the end of the pressure pointer made the latter heavy and unwieldy. The spark method advocated by Bliss (**1**) was also found unsatisfactory by these investigators. Both were therefore discarded in this investigation. Two considerations caused us, furthermore, to abandon the use of the Hipp chronoscope, utilized in the earlier investigation. In the first place, the object of the investigation would be fulfilled as well by a time reading which is accurate to hundredths of a second. In the second place, the use of the Hipp chronoscope made necessary the presence of a second operator. The above method kept the whole procedure under the control of a single operator.

By broken or interrupted time line, the type used in this work, is meant one in which the time is not recorded continuously, but in which the time record is started by the operator in giving the stimulus and stopped by the reactor in breaking the contact at the reaction key. The time thus recorded by the marker is the reaction time. This method does away with the necessity for one or more additional markers with the consequent error involved in dropping perpendiculars to the time line and in comparing corresponding points on the lines traced by the different

markers. It also furnishes a convenient means of determining the point at which the stimulus is given and the point at which the circuit is broken by the reactor. While the marker recorded hundredths of seconds on the smoked paper, the time necessary to count these records was saved by the introduction of the Ewald chronoscope. The chronoscope and marker records were compared from time to time to make sure of their agreement.

A warning signal was used, consisting of the click of a telephone. A diagram of the warning circuit appears in Fig. 3.

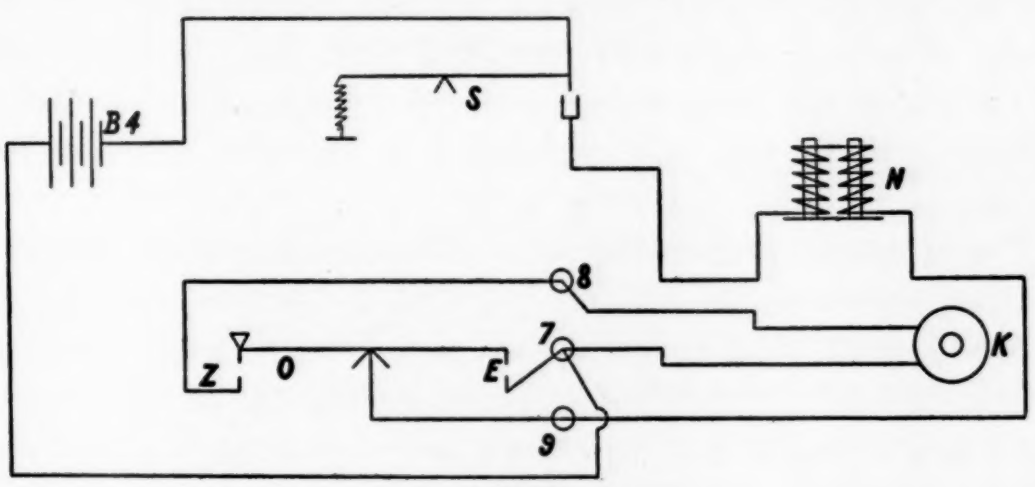


Fig. 3.

Diagram of Apparatus and Connections in the Warning Circuit.

From the battery, B4, the current passes through the outer connections of a Kronecker Interrupter, S, set by comparison with the 100 v. d. fork to vibrate at the uniform rate of ten vibrations per second. This current passes normally through the marker, N, to the post, 9, on key O, through this key to the post, 7, and so back to the battery, B4. The warning signal is given by making the connection at Z on the key, O, the same movement breaking, an instant before, the connection at E. The current then proceeds from post 9 across the connection, Z, to post 8, through the telephone, K, to post 7 and so back to the battery. When the telephone gives the warning the marker stops recording tenths of seconds. When the telephone stops, the marker starts again. In this way a record is obtained of the beginning and the end of the warning signal. It seemed best to have the

length of the following interval (that between warning signal and stimulus) controlled by the operator rather than by a mechanical device giving a constant interval, since the reactor would soon become accustomed to the latter and react at the end of it without reference to the stimulus. The interval varied from one and one-half to two and one-half seconds, with an average of two and one-tenth seconds.

The subject was seated with the forefinger of the right hand on the reaction key, the hand and arm unsupported. A large curtain was hung between the apparatus and the reactor. This curtain did not interfere with the movements of the reactor, and at the same time completely concealed from him the movements of the paper and pressure pointer and the operations of the experimenter. In this way a large amount of distraction was avoided.

The procedure was as follows: The reactor pressed down the reaction key until the pointer rested at the proper place on the smoked paper. The operator then said "ready" and started the electric motor. After about one-half second the warning signal was sounded and after an interval varying from one and one-half seconds to two and one-half seconds the stimulus to react was given. As soon as the reactor had broken the circuit the motor was stopped, the chronoscope time read and recorded on the smoked paper by the operator while the reactor recorded his introspections in writing. Twenty reactions were taken at one sitting. This seldom resulted in fatiguing the reactor. On a few occasions two series of twenty reactions were taken with an interval of about fifteen minutes between.

Special care was taken with the instructions given the reactors, i.e., as to the direction of their attention and the nature of the introspections they were to record. These instructions will be considered in the discussion of the results of the individual reactors. None of the reactors except myself knew anything in regard to his reaction time or the character of his curves until the investigation was completed. In the case of my own records I knew my reaction times but did not know the character of my curves.

Typical records are given in diagrammatic form much reduced in Figs. 4 and 5. Fig. 4 shows a reaction of the gradual type,

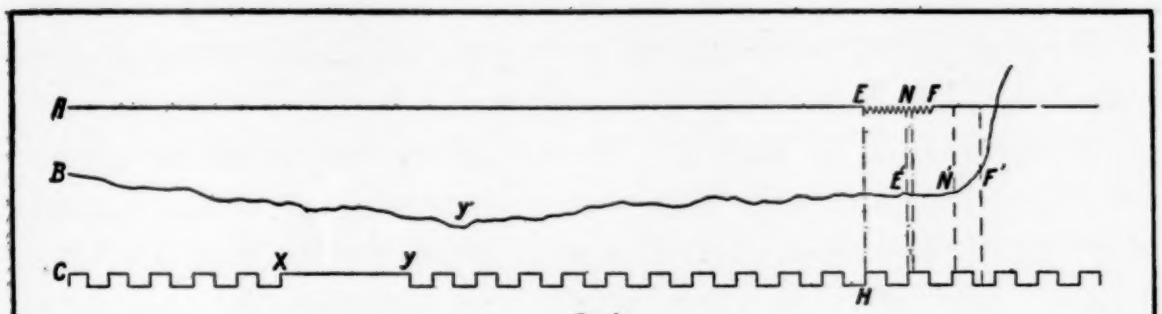


Fig. 4.

A diagram of a typical reaction of the gradual type.

A = Time line.
B = Pressure curve.
C = Warning line.
X = Beginning of warning.
y = End of warning.
E = Point at which the stimulus was given.
F = Point at which the reaction occurs.
E–F = Reaction time.
y–H = Warning interval.
E' = Point on pressure curve corresponding to E.
F' = Point at which curbut was broken.
N' = Point at which movement began.
E–N = Corrected time.
y' = A definite change in the direction of pressure due to the warning signal.

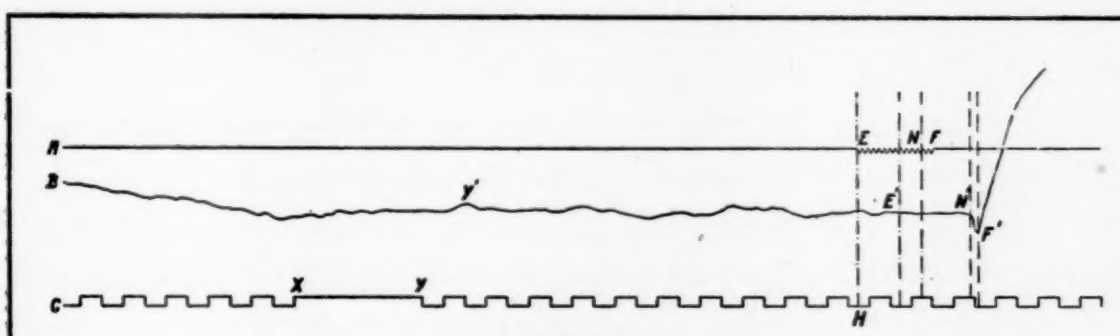


Fig. 5

A diagram of a typical reaction showing the antagonistic form.
The pressure pointer is represented as 10 m.m. in advance of the other pointers.

A = Time line.
B = Pressure curve.
C = Warning line.
X = Beginning of warning.
Y = End of warning.
E = Point at which the stimulus was given.
F = Point at which the reaction occurred.
E–F = Reaction time.
Y–H = Warning interval.
Y' = A special wave due to warning.
E' = The point on the pressure curve corresponding to E.
F' = The point on the pressure curve where the curve was broken.
N' = Point at which the antagonistic reaction began.
N = Point on time line corresponding to N'.
E–N = Corrected time for the beginning of movement.

to be explained later; Fig. 5, a reaction of the antagonistic type. In both figures A represents the time line, B the pressure curve and C the warning line. The two time lines, A and C, were placed one at the top, the other at the bottom, to serve as guide lines in reading the changes in pressure. Point E on the time line, A, represents the instant at which the stimulus was given and point F, that at which the reaction occurred. The distance between these two points, E-F, is the reaction time indicated in hundredths of seconds. Point X on the warning line, C, marks the beginning of the warning signal and point Y its

end. The two markers tracing the lines A and C were placed in line with each other. By dropping a perpendicular from the point, E, to the line, C, at H, the length of the warning interval —the time between the end of the warning signal and the stimulus—could be measured by counting the number of tenths of seconds between Y and H. In all tables the "warning time" refers to this interval. The warning signal itself lasted on an average three-tenths of a second. With the reaction key depressed, the pressure curve was traced between the two time lines. In order not to strike the time markers in its excursions, the pressure pointer was given a position not vertically in line with them, but horizontally slightly removed. In any one series of records this displacement which, of course, had to be allowed for in reading the curves, remained constant.

Since the pressure pointer did not, however, describe a line perpendicular to the two time lines, but an arc of a circle, and since the relation of this arc to the time lines was not constant throughout the investigation, it was necessary to devise an instrument for measuring at any time the horizontal displacement of the marker for any point of its arc. This is shown in Fig. 6. Two accurate steel rules, A and B, were fastened parallel to each other with an intervening space of 25 mm. by riveting them to two brass plates, P and P′. P′ is shown only by broken lines in the figure. Two other brass plates, one of which is shown at R, were grooved so that when screwed together over the rules they would slide back and forth with considerable friction. The face, OM, was made straight and perpendicular to the rules. Upon the brass plate, P′, was riveted a narrow tongue of steel, G. In the strip of brass, U, was cut a long slot, ZZ′, to fit this tongue. U could then be slid up or down in a direction perpendicular to the rules and fastened in any desired position by the screw, S. The edge, TT′, of U was straight and perpendicular to the rules, while the edge, XY, was made to correspond exactly with the arc described on the smoked paper by the pressure pointer.

At the beginning of each series of reactions a record was taken of the horizontal displacement of the arc of the pressure

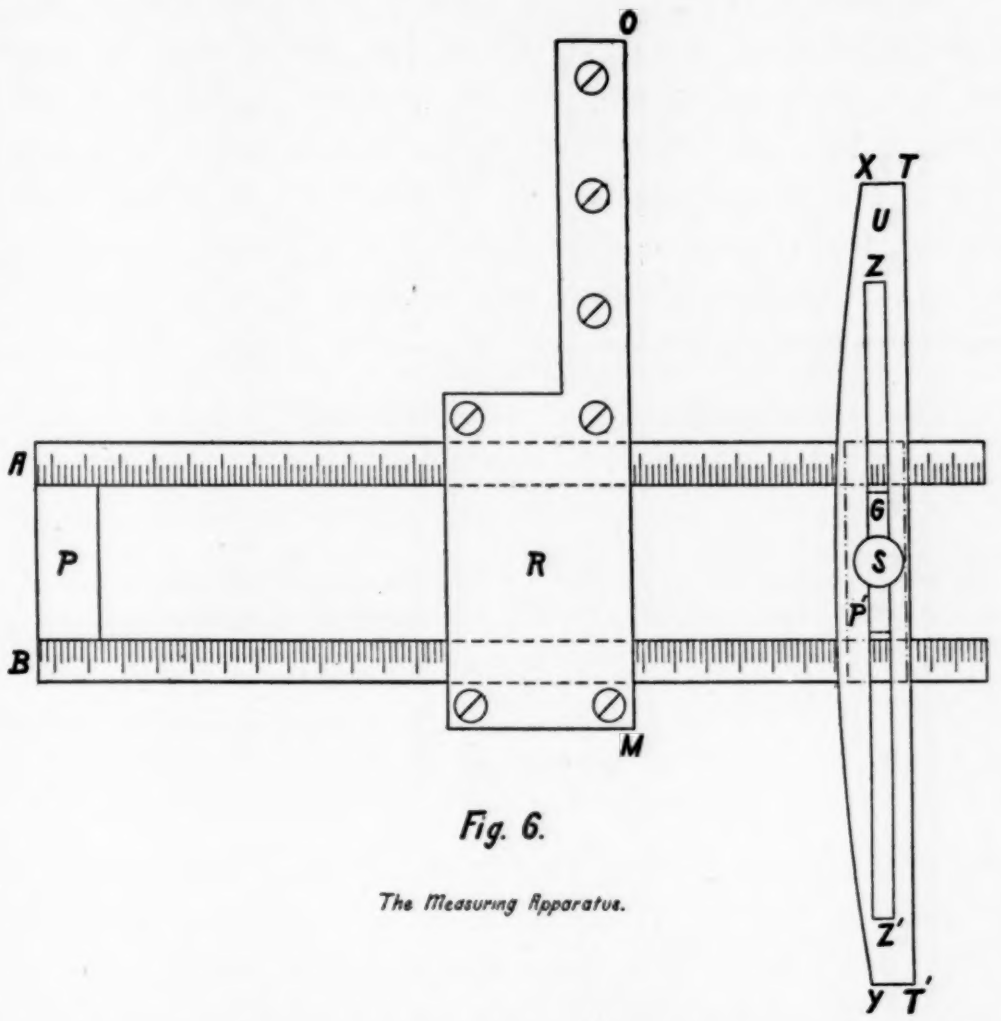


Fig. 6.

The Measuring Apparatus.

pointer from the time markers by starting the latter and moving the pointer up and down while the paper remained stationary. A record of this sort is shown in Fig. 7. To set the measuring instrument properly the upper edge of the rule, A, was squared with the line A (Fig. 7). The brass strip, U, was moved up and down until the curved face, XY, exactly coincided with the curve, XX′ (Fig. 7). The brass plate, R, was then moved towards U until the edge, OM, cut the marks, Y and Z (Fig. 7). The horizontal distance between OM and a given point on XY (Fig. 6) then represented the difference between the positions of time markers and the position of the same point on the arc of the pressure pointer. Recurring now to Fig. 4, with the instrument thus set, we may easily see its use

in reading records. If the upper edge of the rule, A, is squared with the line, A (Fig. 4), in such a way that the edge, OM passes through the point, F, where the circuit was broken, the edge, XY, then represents the arc at some point of which the pressure pointer lay when the circuit was broken. This point is shown at F′. Recurring to Fig. 5, it will be seen that a similar procedure would enable one to mark on the time line the exact point, N, at which the movement began in an antagonistic reac-

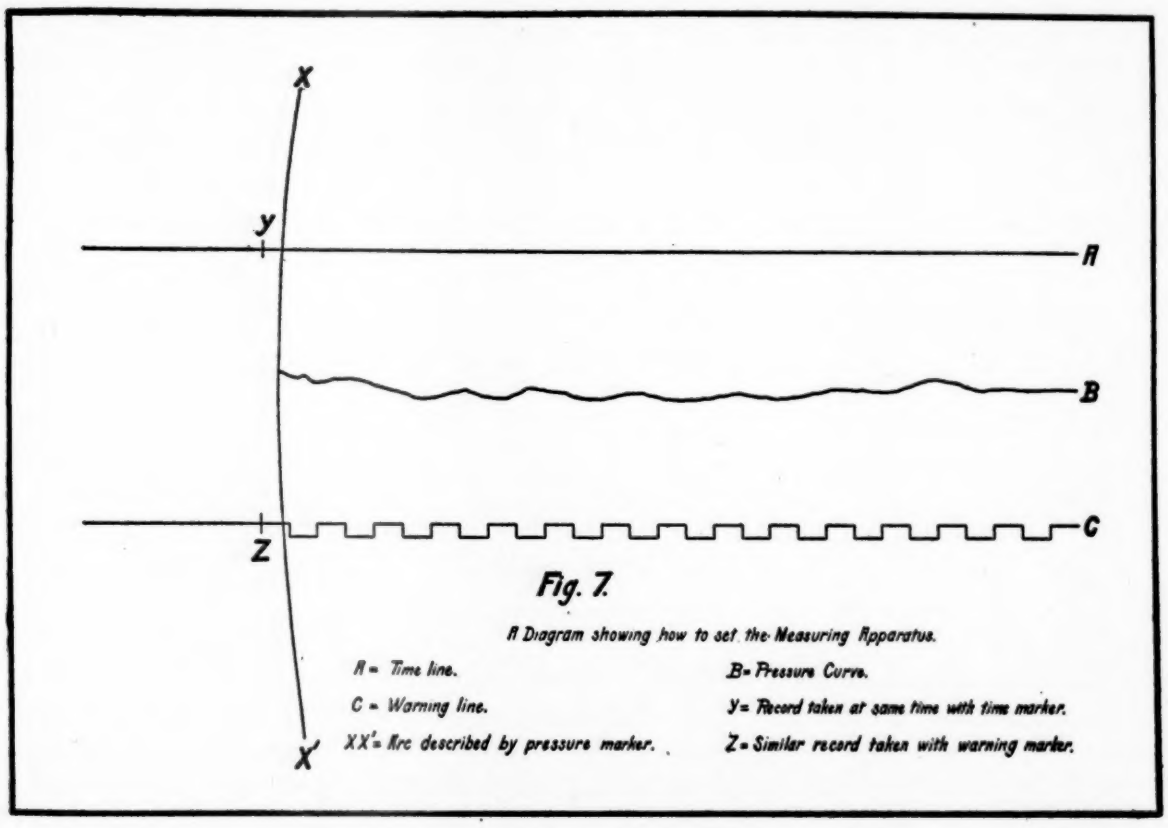


Fig. 7.

A Diagram showing how to set the Measuring Apparatus.

A = Time line. *B = Pressure Curve.*

C = Warning line. *y = Record taken at same time with time marker.*

XX' = Arc described by pressure marker. *Z = Similar record taken with warning marker.*

tion. Here, of course, the arc, XY, of the instrument is first brought to the point on the pressure curve, N′, where the movement began; the straight edge, OM, would then cross the time line at the synchronous point. By the same procedures points E and E′ (Figs. 4 and 5) may be determined.

Smith (**5**) encountered difficulties just here. "In analysing and measuring the curves," he says, "it has been assumed that the apex of the antagonistic curve corresponds to the point of time at which the contact of the electric key is broken in reacting by the chronoscopic method. This assumption is perhaps not entirely correct, but if the apex be not chosen it would be difficult to find any other point on the descending curve which

can be more certainly and accurately determined" (p. 51). It may be readily seen that by the use of the broken time line and some such measuring device as that described, the point on the pressure curve at which the circuit was broken can be accurately determined in any form of reaction.

Such a device does not, however, do away with the difficulty of determining the exact point at which the reaction movement itself began since, as Smith also noted, the reaction (pressure) curve often shows undulations before the real response to the stimulus begins. This difficulty will be seen more fully when we come to describe the different types of curves. It would, however, certainly be less with the spring type of reaction key than with the tambour, or rubber tube used by Smith since, in records taken with a tambour the inequalities are always somewhat softened, becoming gradual and rounded. In the spring type a sudden change in the direction or amount of pressure is indicated by a sharper change in the direction of the pressure curve.

Further trouble arose, however, here. When the measuring instrument just described was applied to the curves it was found that the point at which the circuit was broken did not correspond to the point at which the reaction movement began, even in the cases of a simple, quick, upward movement by the reactor, i.e., in reactions where there were no complicating preliminary undulations, or antagonistic movement before the upward release.

Figure 4 shows the amount of this error in a reaction of a more gradual type. The point F′ on the pressure curve represents the point at which the circuit was broken, stopping the time line. This point can be seen to be some distance up the curve. N′ represents the point where the upward reaction movement began. If we make the necessary correction backward to the time line at N, we see that in this particular reaction it would be necessary to subtract nearly one-third of the chronoscope time to find the time at which the reaction really began. This error, due to the fact that the large spring was really faster, in our experiments, than the beginning of any upward movement of

any reactor, so that the spring followed the finger up for a short distance before the movement became rapid enough to break the circuit, necessitated a correction in all the reaction times. That the error was due to the large spring and not to the small spring fastened to the key itself was determined as follows: the large spring was clamped rigidly in position and a series of reactions taken with the small spring alone; the point at which the circuit was broken then corresponded exactly to the point at which the upward movement of the key began. Experiments were also tried which proved that the error was not due to the latent time of any other piece of apparatus in the reaction circuit.

This error was not a constant one, but varied directly with the rate of movement; the faster the upward movement the less the error. Since this gave a means of determining the speed of the final movement more quickly and accurately than would be possible from an inspection of the curves themselves, the error proved rather an advantage than a detriment. In the case of the more marked antagonistic reactions, the error did not appear; that is, the chronoscope time corresponded to the beginning of the upward movement of the pressure marker after the sharp downward movement. This was undoubtedly due to the sharp downward push to the spring before the finger was removed, the inertia thus given the spring allowing the finger to start upward and the small spring to break the circuit at the same instant that the large spring started upward. In a few cases of a very marked antagonistic reaction, the spring continued its downward course even after the circuit was broken.

More than twenty-seven hundred graphic records were taken in the course of the investigation. These records have been treated quantitatively and qualitatively; quantitatively as to the reaction times, qualitatively as to the character of the movements. The quantitative tables (see, as typical, Table III, p. 89) show three sets of times. The column marked "Chronoscope," includes the averages of the total reaction times (from the giving of the stimulus to the breaking of the circuit) as recorded by chronoscope and marker. The column marked "Cor-

rected," includes the averages of the actual reaction times, or the times elapsing between the giving of the stimulus and the beginning of a sharp *upward* reaction movement. The final column of times, marked "Movement Began," records the averages of the times as corrected for the antagonistic movements. It includes also a few corrections made for gradual reaction movements and for the double type of reaction. This time, then, represents that elapsing between the giving of the stimulus and the beginning of *any* reaction movement, whether in an upward or downward direction. The tables also include the average warning time.

The quantitative results have been treated in this elaborate way in order to make possible a careful comparison between form of movement and reaction time. The custom observed by many experimenters of omitting from the average the first two reactions and any others which appeared to the reactor to be abnormal has not been followed. The character of the movement in such so-called abnormal reactions is of as much interest in an investigation of this sort as the character of the normal reactions. Only those times have been omitted from the average which were incorrect because of an error in procedure or because of extreme distraction of the reactor. Our inclusions have, of course, increased the averages and mean variations in the tables presented. The mean variations appearing in the column "Movement Began" are, furthermore, of little value for comparison with the work of other investigators since they are increased by the presence of the antagonistic form of movement. Where times and variations are referred to in the later discussion, "corrected" times are meant.

To make the reading and classification of the pressure curves possible, the record for each reaction was mounted on a separate sheet of paper. These sheets were twice the width of the records to give space at the side for notes. Mounted in this way, the records could be spread out for a quick general survey of the whole series. They could also be taken out of their order and grouped and classified according to their characteristics.

For the purpose of analyzing the form of movements, the reaction period was divided into five parts: the period before the

warning signal, the period during the warning signal, the period from the warning signal to within about four-tenths of a second of the giving of the stimulus, the period from within about four-tenths of a second of the giving of the stimulus to the beginning of the reaction movement, and, lastly, the reaction movement itself. The first four parts of the reaction period were classified as to the direction and general "character" of the pressure. The final reaction movements themselves were classified according to the type of movement made. The tables summarizing the results (see, as typical, Table II, p. 77) include a key which describes the various "characters" of the movements treated. The number appearing at the top of a given vertical column of the table indicates the number of the series. A number appearing in the column itself indicates that that particular series manifested that number of times the characteristic stated in the key at the left end of the horizontal line on which the number stands. Thus, the number appearing in Table II, vertical column No. 1, opposite the rubric "no change at warning," indicates that in 5 cases in series I there was no change in the form or character of the pressure at the warning signal. Following along and horizontal line in the summary tables, from series I, one can trace the change or development, in a given pressure characteristic, through all the succeeding series. Comparing these qualitative summary tables with those showing the average reaction times for the same series, a quick judgment can be made of the relation between the form of movement and the length of the reaction time. The totals for all series are given in the column at the right side of each qualitative table. Each table also contains at the bottom a statement of the number of reactions considered in each series separately, and in all series together.

III. DETAILED DISCUSSION OF REACTORS AND REACTIONS

Reactor M.

Reactor M. was a graduate student in Yale University. He was not distracted by the apparatus even at the outset of the experiment and was able to keep his mind well upon the work in hand—facts observed not only by the operator but brought

out clearly by the introspections. No instructions were given M. at the outset either as to the direction of attention or as to the rapidity of reaction. He was told to remove his finger from the key on hearing the stimulus. At the top of the first sheet used by reactor M. for introspections the operator wrote: "After each reaction introspect carefully any points which seem to you of importance in understanding the reaction." Nothing was said during M.'s series in regard to the introspections.

The arm movement made by M. in reacting during the different series was carefully watched. It was always the same—a quick upward jerk of the forearm from the elbow. In this movement neither shoulder nor wrist played any appreciable part, and hand and fingers acted practically as one.

Thirteen series, comprising 259 reactions were secured from M. without further instructions or knowledge of results. These reactions covered a period of six weeks. Eight of the thirteen series were taken in two consecutive weeks. In only one case, series II and III, was there more than one series taken in a day. In this case, series III showed such longer times and greater variations than the normal that the attempt was not repeated. Since M. (Table I) gave practically no antagonistic reactions (only 7 in all, and these of rather doubtful character), only one correction therefor was made in the time. The column marked "Corrected" corresponds, therefore, also to the time of the beginning of movement. These corrected times are incredibly fast. The reason, which will presently be discussed (see p. 83) can be understood only by reference to the character of the reaction movement.

An inspection of Table I does not show a regular decrease in the average times and mean variations due to practice, the longest times occurring to series I (92σ), III (96σ), XIII (81σ). Series III was the second series of twenty reactions taken in one afternoon. Series II, taken just before it, shows both a markedly smaller reaction time and a small mean variation. Series XIII was taken when M. was tired from examinations and lack of sleep. From series III through series IX the average time was gradually shortened from 78σ to 53σ. Series X and XI have

TABLE I.—*Summary of average times and mean variations. Reactor M.*

No. of Series	Warning time seconds	Chronoscope Time sigmas	Chronoscope Var.	Corrected Time sigmas	Corrected Var.
I	2.3	122	13	92	13
II	2.4	100.5	10.2	67	13
III	2.0	124.4	18.1	96.5	16.8
IV	2.0	106.5	10.5	78.	13.9
V	2.3	108	17.2	72.6	22.7
VI	2.0	104.5	13.5	67.8	20.2
VII	1.9	99.1	15.3	64.4	13
VIII	2.0	97.3	13.3	67.6	13.7
IX	2.1	88.5	10.6	53.2	15.6
X	2.2	92.3	18.71	61.3	17.9
XI	2.2	99.7	16.2	67.4	25.2
XII	2.2	99.4	16.8	52.2	28.9
XIII	2.2	123	8.3	81.7	9.7
Averages	2.2	105	13.97	70.9	17.2

somewhat longer times. The time of series XII, taken when the reactor was in a hurry to catch a train, is the shortest of all the series, 52σ. M. stated at the end of this series that he thought this had not affected his times. It is apparent that the averages in these faster series are reached at the sacrifice of regularity. This is shown by a comparison of the mean variations. Series XII, with the shortest average corrected time (52σ), has the largest mean variation, 28.9. In series XIII, in which the reactor was tired and in which the average time is long (81σ) the mean variation drops as low as 9.7. Of the rest of the series, the same type of difference appears, generally, between the series giving high and those giving low reaction times.

Turning to an account of the form of the reaction movement made by M. (Table II), we find that he was a very steady reactor. The pressure curves, though showing marked changes in direction at the critical points, are very regular in appearance and quite free from minor inequalities, such as waviness. In detail, the following characteristics emerge from M.'s 259 reactions: in the period preceding the warning signal there were 150/259 cases of steady pressure (level line), 72/259 cases of increase in pressure (falling line), 31/259 cases of decrease in pressure (rising line) and practically no unsteadiness (wavy line, 6/259 cases). In the majority of cases, then, the characteristic line in this period was steadily level.

TABLE II.—*Summary of forms of movement. Reactor M.*

Key — Series No.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	Total	
Rise before warning	2	1	4	1	2	2	3	1	1	1	4	6	3	31	
Fall before warning	6	7	2	7	3	6	6	7	7	9	4	4	4	72	
Level before warning	11	10	14	12	16	11	11	12	11	10	12	8	12	150	
Wavy before warning		1				1			1			2	1	6	
Change at warning	14	13	10	15	13	16	19	14	15	17	17	16	14	192	
No change at warning	5	6	10	5	8	4	1	5	5	3	3	4	6	66	
Reacted to warning														0	
Marked rise after warning				1		1			1					3	
Medium rise after warning	2	4	1	2	2	1	2	3	3	2	1	3		26	113
Slight rise after warning	3	8	2	6	6	5	4	5	7	6	12	12	8	84	
Marked fall after warning														0	
Medium fall after warning									1	1				2	7
Slight fall after warning	1			1	1			1	1					5	
Level after warning	13	7	17	9	11	13	14	11	8	11	7	2	9	132	
Wavy after warning				1	1							3	3	8	
Marked rise towards end		4	2		1	5	1	1	2	1	1	9		27	
Medium rise towards end		4	1	5	2	7	5	2	7	7	8	5	5	58	146
Slight rise towards end	7	1	4	4	8	4	4	5	5	2	6	3	8	61	
Marked fall towards end														0	
Medium fall towards end		1					1			1				3	7
Slight fall towards end							1	2		1				4	
Level towards end	10	8	11	9	8	2	7	7	6	6	5		6	83	
Wavy towards end	2			3	2	2	1	2		3	2	9	1	27	
Reacted before stimulus			2				1	1		1		1	1	7	
Sharp reaction	19	17	20	20	19	17	18	16	18	19	18	12	20	233	
Gradual reaction		1				2	2	1			1	6		13	
Slight antagonistic reaction					1			1		1	1			4	
Marked antagonistic reaction														0	7
Gradual antagonistic reaction									2			1		3	
Double reaction		1			1	1		1				1		5	
Number of reactions in series	19	19	20	20	21	20	20	20	20	20	20	20	20	259	

The warning signal produced a change in the direction of the curve in 192/259 cases, the steady line altering into a gradual rise, which indicates a gradual decrease in pressure. From the warning signal on through the next second and a half the cases are about equally divided between an even pressure (132/259 cases) and a slight or medium decrease in pressure (113/259 cases). There were few cases either of a marked decrease in pressure during this interval (3/259 cases) or of a marked increase (7/259 cases).

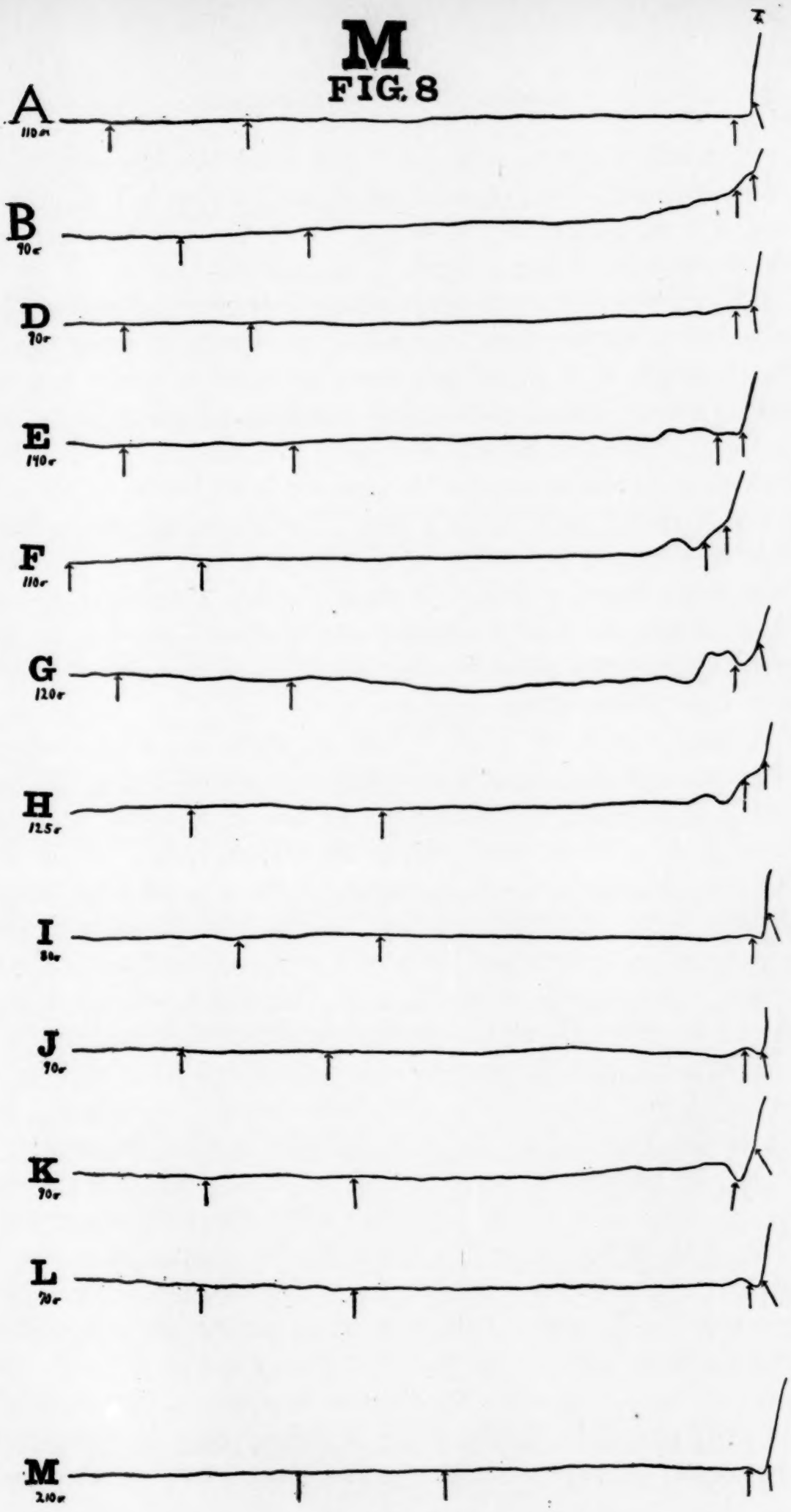
In the period covered by the last one third to one half second before the final reaction movement[1] the most marked characteristic is a decrease in pressure (146/259 cases). These cases are about evenly divided between a slight rise (61/259 cases) and a medium rise (58/259 cases) towards the end,[1] except for 27/259 cases of a very marked rise. In 83/259 cases an even pressure is maintained towards the end. The proportions have changed, however, since the period before, where steady pressure predominated. There are almost no cases of increased pressure towards the end (7/259 cases), and a few of unsteadiness, (27/259 cases).

The final reaction movement itself was in almost every case (233/259) of the sharp simple type shown in Fig. 8, type A. The drawings of the curves in this and the later Figs. 11, 13 and 16 are pantograph reproductions much reduced. The two arrows to the left, on the pressure curves, represent the beginning and the end of the warning signal; the two to the right represent the points at which the stimulus was given and the circuit broken, respectively. Aside from these reactions of type A, Fig. 8, there are a few cases of the gradual type (13/259) shown in type B. These gradual reaction movements occur in the case of M. in the fast rather than in the very slow reactions, and an examination of the curve shows that the reaction was begun before the stimulus was given and then gradually completed. There are no true

[1] By "final reaction movement" is meant the reaction to the *stimulus*. The phrase "towards the end," repeatedly occurring, refers to that part of the pressure curve just preceding the beginning of the "final reaction movement."

M

FIG. 8



Reactor M.—Pantograph reductions of pressure curves. The letters stand for the types as described in the text. The numbers under the letters represent the reaction time.

antagonistic reactions, although 7/259 cases have the antagonistic appearance. Four of these are shown in types I, J, K, and L and will be explained presently. There are five reactions of the double kind shown in types F, G, and H.

The curves give, as a whole, clear evidence that reactor M. exhibited a definite type of reaction movement in these series. Furthermore, M.'s type of movement appeared *naturally,* without any instructions and without his knowing anything about the form of movement he was making. The uniform type of the final reaction movement, which appeared in all but 26 of the 259 cases, is itself a most striking fact. Can we explain the definite characteristics of M.'s form of movement in any way, or relate them to the reaction times? Is there, further, a definite development of this form of movement during the series, that is, are the characteristics shown in the summary more marked in the later than in the earlier series?

A careful study of Table II does not show any such development through practice; there appears no steady or regular increase or decrease in the number of any of the characteristic parts of the pressure curve during the various series. A similar fact was also found for M.'s reaction times. A definite relation between form of movement and reaction time appears at the outset and is maintained quite constantly throughout all the series. Comparisons of earlier with later series will make this clear. In series II, with a short average time, there were 12 cases of a rise after the warning. In series I and III, with longer average times, only 5 and 3 such cases respectively appear. In the period just before the final reaction similar relationships occur. In the last series, XIII, which shows long times, there are no cases of a marked rise preceding the final movement. Series XII, moreover, with a much shorter average time, has 9 cases of a marked rise at this point. This relation between the time and the character of the movement towards the end of the pressure curve is shown by the curve plotted in Fig. 9. Here the upper curve, A, represents the changes in corrected time through the series plotted in sigmas, while the lower curve, B, represents the number of rises towards the end, just preceding the final

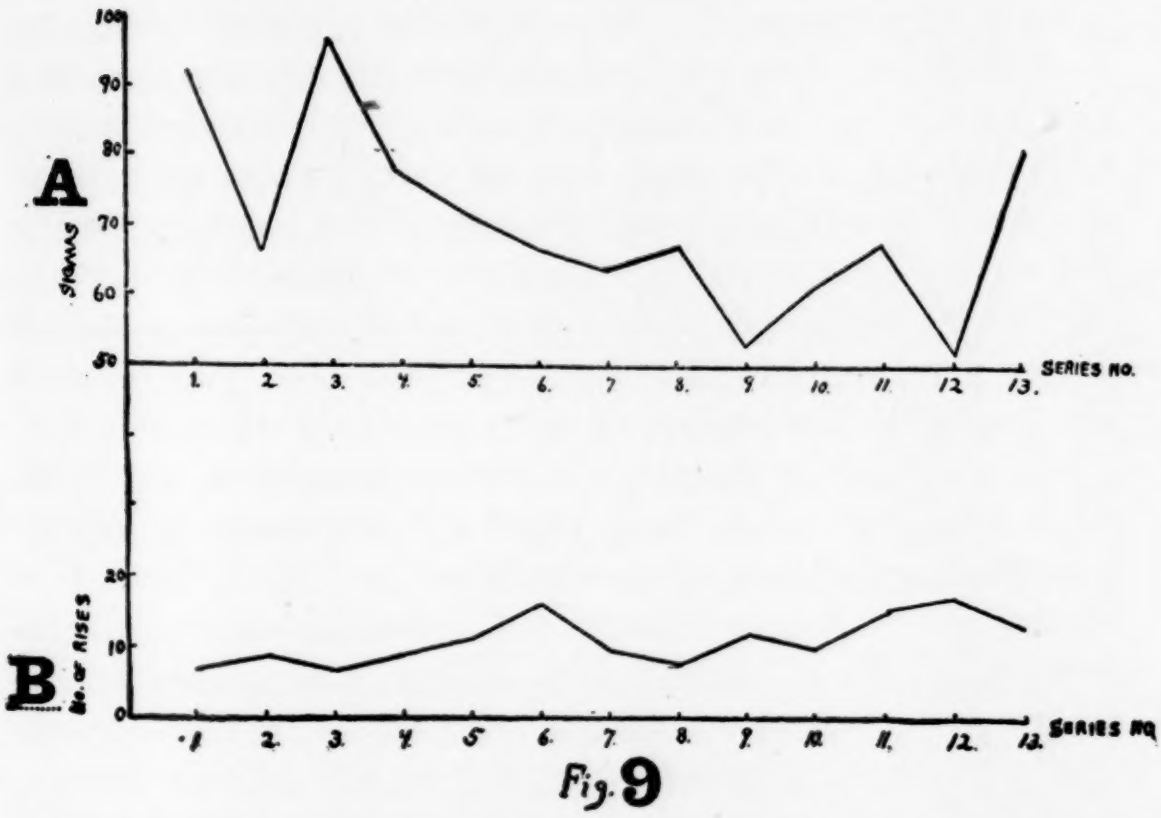


Fig. 9

Reactor M.—Showing the relation between the number of rises in pressure curves towards the end of the records and the length of the reaction time. Curve A. represents the reaction times through the series. Curve B. represents the frequency of the rises "towards the end."

reaction movement. In almost every case it can be seen that as the time curve rises, the curve showing the number of rises towards the end, drops. Where the time curve drops the curve showing the number of rises towards the end rises.

If we compare the character of the movement in each reaction with the introspections we find that the sharper the rise in the line from the warning signal on to the end, the stronger the attention. M. stated that this stronger attention was always associated with a tense muscular preparation. This increase in preparation, with the corresponding decrease in pressure, was particularly evident just after the warning signal and towards the end of the reaction period. These rises towards the end show a strained kinesthetic expectation of the stimulus. The lower curve, then, in Fig. 9, represents the degree of expectancy or of anticipation of the coming stimulus. We can better understand these characteristic features of M.'s pressure curves if we express the facts in a somewhat different way. In the period before the

warning M. sat passively holding down the key with the muscles innervated only to the extent of accomplishing this purpose. The warning signal started a definite muscular preparation, shown by an increasing muscular strain not only in the muscles of the hand and arm but in those all over the body. This increasing strain was usually accompanied by a slight rise of the forearm. As the time for the expected stimulus approached, this upward movement became more marked and at last the reaction took place unless it was checked by a voluntary effort on the part of the reactor.

This muscular preparation, if partially controlled, may give rise to wavy lines as in type E, Fig. 8. It may complete itself by a medium or marked rise towards the end, as in D and B. It may go so far as partially to begin the reaction movement before the stimulus occurs, a fact then realized by the reactor and checked in time to allow for a second reaction when the stimulus comes (reactions of the "double type"), as in F, G and H. In H, it can be seen that even a second reaction had begun before the stimulus was given. If we compare these types with the introspections we find for type F: "Started before stimulus." For G: "Slow. Attempted to react too soon. Warning period seemed long." For H: "Slow. Came near reacting." These then are strong instances of checked premature reactions.

To understand the few reactions in M's series which appear to be antagonistic, types I, J, K and L, we will refer once more to the introspections. For I we find: "Tendency to react"; for J: "A forced effort to be calm"; for K: "Hard to hold down. So much energy expended in holding down, not enough left for reacting"; for L: "Nearly reacted before stimulus." These forms then are closely allied to the double type. One would suspect that, had the stimulus been delayed an instant longer in such a form as type K, it would have given rise to such forms as F. or H. These apparent antagonistic reactions occurred when the anticipatory reaction was realized and the reactor attempted to control or check it. In each of these cases the movement was not the effect of the stimulus but had begun before it, as in type K, or too soon after to be

explained by it, as in types I, J, and L. Although the reactor was aware of the muscular preparation and the impulse to react, he was not aware of the upward movement of the arm in the period preceding the stimulus and was much surprised at this when shown the curves after all the series had been taken.

The reason for the very fast corrected reaction times may now be better understood (see p. 75). We found M's typical form of final reaction to be the sharp upward movement. When, however, there was a high degree of muscular preparation before the stimulus, this typical reaction resembled more the gradual type (see p. 78) because of the pronounced rise of the line preceding the final reaction movement. This is shown in the difference between types A and B, Fig. 8. In this latter type where did the reaction movement begin? Certainly before the stimulus occurred, though the gradual upward movement did not break the circuit. Such an upward movement would have completed itself with or without the stimulus, unless the whole character of the attention had been changed and directed to an effort to hold the finger down. It is evident then that the reaction time, in this gradual upward type of movement, would depend on the point of the rise at which the stimulus occurred. In some cases the stimulus came so late that the reaction was nearly completed, even the "Chronoscope" time being therefore very short, at times as low as 60σ. If in such a reaction the time is corrected to the beginning of movement it would be reduced to zero. Even in type A curves (which formed the bulk of M.'s reaction records) there is a steady rise in the curve before the stimulus, giving short reaction times, although not so extremely short as in type B.

With an apparatus allowing such a form of movement the reaction time could not be understood without reference to a graphic record of the form of movement. Since with reactor M. this form of movement was perfectly natural, any apparatus which did not allow it to occur would have occasioned an artificial form of movement and turned the natural direction of the attention from a muscular preparation to react to an attempt to keep the contact on the key unbroken.

Let us turn now to the historical classifications of reactions established by Lange and his followers to see if we can classify reactor M. by any of these. Those reactions having short times with small mean variations, in which there is a muscular strain and frequent wrong or premature reactions, are classified as motor reactions. When, in addition, the reactor's introspection shows that his attention was on the movement to be made and not on the stimulus, we can be sure that the reaction is of Lange's motor type. Those reactions, on the other hand, having long times and large mean variations, with a definite sensory strain (that is, a strain in the sense organ rather than in the muscle) and no wrong or premature reactions, but among which at times, delayed reactions occur, are classified as sensory reactions. To these criteria would be added the introspection of the reactor that his attention had been on the expected stimulus and not on the movement to be made.

The description of reactor M. given above brings him clearly under the head of motor reactors. M.'s reaction times are very short, even below the 100-120σ determined by Lange as the average range of motor reaction time, and the mean variations are low, most of them below 15. Seven cases of reaction before the stimulus occurred scattered through five series. According to the introspections each of these cases was due to strained attention and extreme muscular preparation. Several special trials were made at unexpected times with a much longer interval between the warning signal and the stimulus. In each of these cases M. reacted before the stimulus, stating afterward that he "could not hold on any longer." In many cases, too, of the regular series in which a reaction time was recorded, both the shortness of the time and the sharp rise of the pressure curve before the stimulus was given, indicate clearly that these reactions were really begun before the stimulus occurred.

If we turn to M.'s introspections we find even clearer proofs of the motor type. Several times during the course of the investigation M. was asked to write at the close of a series his introspections on the direction of his attention. These statements did not change throughout the investigation: "I sit waiting passively

for the warning signal with my attention turned in that direction. After the warning signal for perhaps one second I continue to sit passively. At about this point I begin to think it may be time to react and my muscles seem to tighten all over in preparation. My attention does not seem to be upon the stimulus which is coming nor upon my finger; it seems to be centered in a definite muscular preparation for a quick reaction. Although I do not pay any attention to the expected stimulus, yet if it is delayed I can only keep my finger on the key with difficulty. The reaction itself seems to be almost automatic. I make the necessary muscular preparations and the stimulus sets it off. Many times I am surprised to find myself reacting and to learn that the stimulus has occurred." At times M. stated that after the reactions he could recall that the stimulus had occurred. These statements tally, as we have seen, with the character of the pressure curves and the reaction times. Of the introspections recorded by M. after the individual reactions the most common type is "hard to hold my finger on the key" or "anxious to react." These two statements occur over 150 times out of 259 reactions.

M. then is clearly a motor reactor, and *naturally* so, since this type of reaction was assumed without any instructions. This brings him not only under Lange's classification but also under that of Baldwin's "natural types."

These facts of classification are of special interest since M. exhibited a definite *form* of reaction movement along with his natural motor type of reaction,—a decrease in pressure from the warning signal to the end of the record, the final movement in response to the stimulus being a simple sharp rise. This form of movement did not, further, develop by gradual practice but was, from the outset, related to the strength and direction of the attention and to the attendant varying degrees of muscular preparation. Any marked divergence from it, such as the double or partial antagonistic types, arose from an effort to check this normal tendency.

Some check experiments were tried with M. with explicit instructions on the direction of his attention. Forty-one reactions were had in which he was instructed to allow the movement to

take care of itself and to turn his attention entirely on the expected stimulus. Thirty reactions were taken with instructions to concentrate the attention on the movement and not to pay any attention to the stimulus.

There was a marked difference in time between the two series. The average corrected time for the sensory series was 144σ while that of the motor series was 97σ. The mean variation for the motor series was 15 and that for the sensory 22. One reaction before the stimulus occurred in the motor but none in the sensory series. In the motor series M. was instructed to introspect on the *time* and on the direction of his attention and in the sensory only on the direction of his attention. The difference in the time of the two series and in the introspections shows that M. succeeded in establishing a corresponding difference in the type of attention. At the close of these series he stated that the motor series in every case appeared to be much more natural than the sensory, and seemed just like the earlier series.

The character of the movement in the motor series is identical with that in the earlier series. The pressure was steady in the period before the warning in 18/30 cases. There was a marked change in the direction of the pressure-curve at the warning in 28/30 cases. The pressure was decreased slightly or to a medium extent in the period after the warning in 20/30 cases, and to a marked extent towards the end of the record in 22/30 cases. There were no cases of increased pressure in this period. All but two of the final reaction movements were of the simple sharp kind, shown in type A, Fig. 8. There was one reaction of the gradual type and one reaction of the double type.

The summary of the sensory series shows the form of the movement in the critical parts of the record to be changed. In the period before the warning signal the cases are about equally divided between an increase and a decrease in pressure. There is a change in the direction of the pressure-curve at the warning signal in 38/41 cases. After the warning signal there are only 9/41 cases of a decrease in pressure, while 13/41 cases of an increase in pressure occur. This is in marked contrast to the motor series. In the period just preceding the stimulus there are

only 5/41 cases of a decrease in pressure, while 15/41 cases of a slight increase in pressure occur. In these last two periods the cases of steady pressure are about equal in number to those of increased pressure. The reaction movement itself in the sensory series was the same simple sharp rise in 39/41 cases. There were two cases of gradual antagonistic reactions shown in type M., Fig. 8. The downward trend of the pressure-curve at the end is quite noticeable in these cases. These two antagonistic reactions were the effect of the stimulus rather than an effort on the part of the reactor to keep from reacting as in the "apparent" antagonistic reactions of M.'s regular series.

These two control series furnish further proof that the motor type of reaction was M.'s natural type, that a definite form of reaction movement accompanied it and that this form of movement changed with the changed direction of attention in the sensory reactions.

Fifty-one reactions were then taken with M. upon an electric break key. He at once experienced difficulty with this key in the motor reactions. His normal tendency to prepare for the final movement by lifting the finger could not be carried out, since the least movement of the finger upward broke the contact on the key. Although the attention was directed towards the finger and not to the stimulus, it was concerned with holding the finger down on the key rather than with the final upward movement. The average motor reaction time with this electric key was 120σ with a mean variation of 15. This is much longer than the average corrected time for the spring key.

M. stated after this series that he did not like the electric break key as well as the spring key. He felt "hampered, as though his finger were held down or tied down." He did not dare raise his finger at all or decrease the pressure on the key. After one series M. stated: "I find that more energy is consumed in pressing on this key than on the spring key. Time is required to overcome this pressure after the stimulus is given. The finger must be held down without any letting up." Not only was the attention turned to an effort to hold the finger down, but the introspections show that the attention was, at times, even drawn

towards the stimulus, since it could not employ itself with a preparation to react.

A few reactions were taken with this same electric break key with instructions to attend to the stimulus. The average time was not increased in this case beyond that in the motor series with the same key. M. found much less difficulty with the electric key in the sensory series and stated that to him such a key seemed better suited to the sensory than to the motor type of reaction.

Such facts as these bring out even more clearly the conclusions already reached concerning M.'s definite natural type of reaction. They show also the marked effect which the different kinds of keys had upon the character of the attention. A key of the spring type appears much better suited to reaction work than the electric key since the latter may inhibit not only the natural tendencies of the reactor, making it impossible for him to react in a normal way, but also the directing of his attention in accordance with instructions.

Reactor H.

We will contrast with these results of reactor M. those of reactor H., also a student in the Graduate School. H. had had no previous training in reaction experiments of any kind, knew nothing of the distinction between the sensory and motor types of attention, was wholly unfamiliar with the apparatus at the outset, and was but little distracted by the new type of movement. Nothing was told H. as to the object of the investigation. He was told simply to lift the finger from the key on hearing the stimulus, and the movement employed by him, as observed by the operator, proved not to differ much from that of M., the reaction movement being a quick, upward jerk of the forearm from the elbow. The same suggestions concerning introspections were given H. that were given M. (see p. 75).

Fourteen series with a total of 280 reactions were secured, without additional instruction or knowledge of results. These series covered a period of eight weeks. The last nine series were taken in two consecutive weeks.

Three columns of times (see p. 72) are given in the quan-

titative summary of H.'s reactions, Table III. Except where expressly stated the "Corrected" time is the one utilized in the text. The "Movement Began" time is of interest only in indicating the amount of time which it is necessary to subtract for the antagonistic form of reaction movement. The time curves

TABLE III.—*Summary of Average times and mean variations. Reactor H.*

		Chronoscope		*Corrected*		*Movement began*	
No. of Series	*Warning time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
I	2.2	173	36	154	32.2	130.8	23.2
II	2.4	176	20.5	172.5	14.8	134.3	22.4
III	2.0	159	20.7	142	18.	124.3	14.9
IV	1.9	147	18.2	138.7	16	104.7	16.7
V	2.0	158.6	22.9	144.8	13.6	128.8	15.1
VI	1.8	137.8	13.2	121.6	12	100.5	15.9
VII	1.8	138.	19.7	123.7	19.9	93.7	23.3
VIII	2.1	130.5	16.2	119	11.2	89	19.4
IX	2.2	131.6	13.4	121	13	93.6	16.7
X	2.2	127	14.2	114.2	14.7	101	12.7
XI	2.2	116.1	14.5	105.3	14.9	81.7	22.6
XII	2.1	133.1	16.7	117.8	16.2	101.6	13
XIII	2.1	131	18.3	124.2	18.2	96.2	16.8
XIV	2.1	120	20	114.7	20.9	81.9	29.1
Averages	2.2	148.4	18.8	129.5	16.8	104.4	18.5

plotted in Fig. 10 show very clearly the relations between the different times. The difference between the upper line representing the chronoscope times and the middle line representing the corrected times, shows the error that had to be subtracted for the speed of the movement (see pp. 71-72). The error is a very constant factor with H. since the two curves correspond very closely. The average error for the entire series was 18σ. The difference between the corrected time curve and the lowest (broken) line representing the time to the beginning of movement, shows the amount of correction which it is necessary to allow for the antagonistic reaction. The average correction, i. e., the time consumed by the antagonistic phase of the movement, was 25σ. Since the amount of correction for the different antagonistic reactions is nearly the same, the difference between these two lower curves represents, roughly, the relative frequency of such

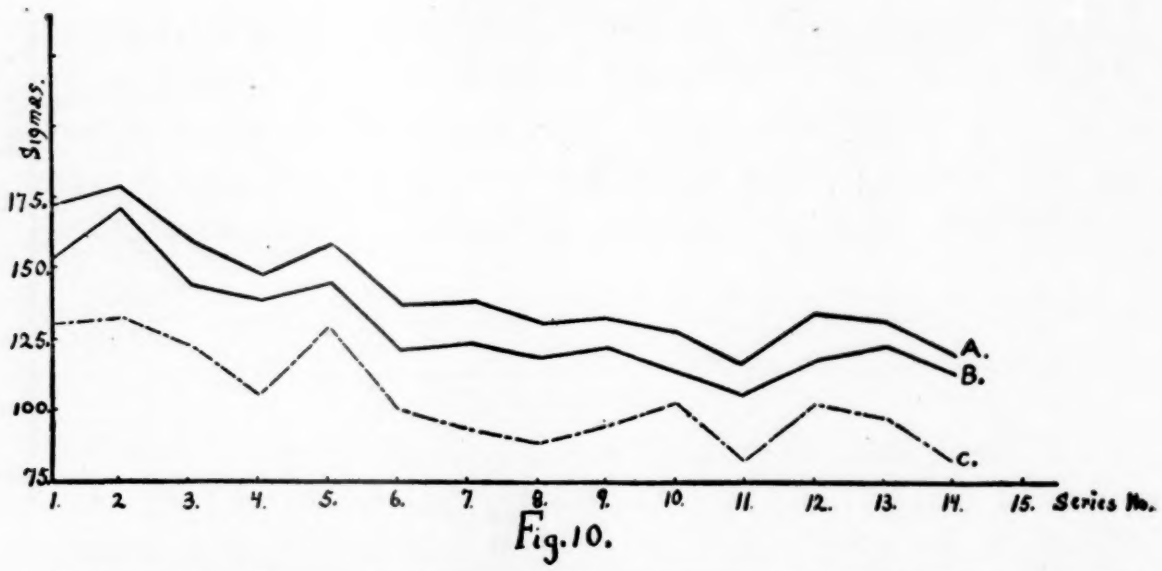


Fig. 10.

Reactor H.—Curves showing the relation between the length of the reaction times through the series.

Curve A. represents the Chronoscope time; curve B. the Corrected time; and curve C. the time to the beginning of movement.

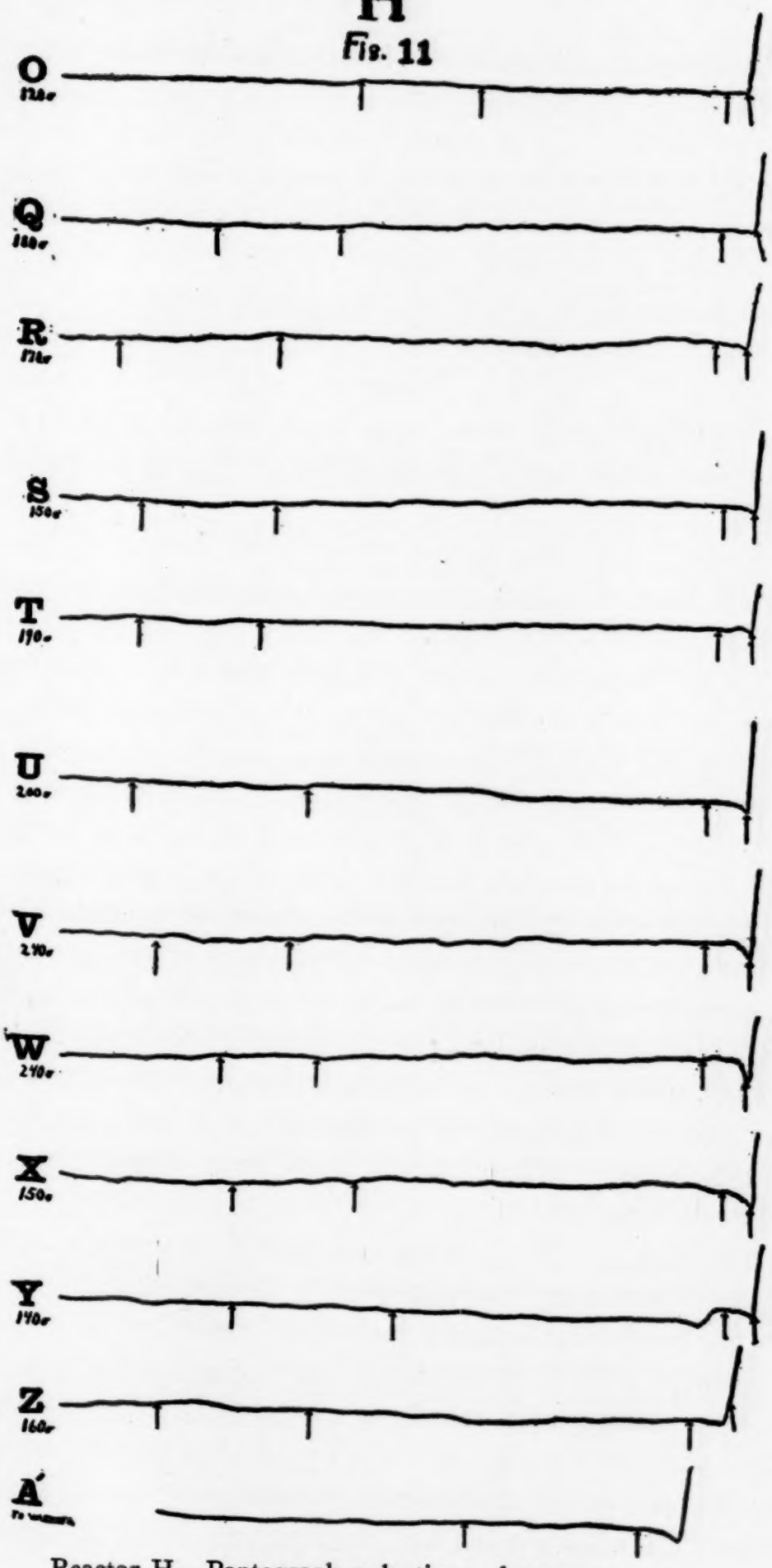
antagonistic movements. For example, there were fewer antagonistic reactions in series I, V, X and XII than in the other series.

The average time for all the series is fast, 129.5σ, and the mean variation is not large, 16.8. From series II through series XI there is a gradual decrease in time due to practice. The mean variation also decreases through these series. The average time increases again in series XII and XIII. In series XII H. had been excused from the middle of a long examination to keep his appointment for the reactions. The introspections show that he could not keep his mind from wandering to the subject of examination. In series XIII he stated that he was tired and nervous.

The qualitative summary, showing the characteristics of the pressure curves traced by H., is given in Table IV. H. is a more unsteady reactor than M. This unsteadiness is due to a nervous trembling of the hand, and appeared to a more marked degree when H. was tired. The most prominent characteristics in the curves are as follows: In the period before the warning signal there were 103/280 cases of increased pressure, the other cases being divided between a steady pressure, 95/280 cases, and waviness, 62/280 cases. The warning signal caused a change in the character of the pressure in more than one-half of the records,

H

Fig. 11



Reactor H.—Pantograph reductions of pressure curves.

172/280 cases. In the period after the warning signal there were more cases of increased pressure (82/280) than of decreased pressure (15/280). The greatest number of cases in this period are steady and level (124/280). Towards the end of the record, before the final reaction, the proportions are not much changed,—76/280 cases of increased pressure; 40/280 cases of decreased pressure and 114/280 cases of level, steady pressure. The final reaction movement is manifestly of the antagonistic type, e. g., types S to W, Fig. 11. There are 195/280 such reactions. There are 68/280 reactions of the sharp type O, 4/280 cases of the gradual antagonistic type Z and 8/280 cases of the double type Y.

Such an account shows very clearly that reactor H. exhibited a definite form of reaction movement and one that he exhibited *naturally*. It differs radically from that shown by M. Was this form of movement developed through practice? The reaction *times* of H. show the effects of practice in the course of the series more definitely than did those obtained from M. As to the *form*, neither manifests any regular change or development due to practice; both show their characteristic variations in form in the early as well as in the late parts of their total series. But whereas M.'s final reaction movements were either sharp or gradual in form, with few antagonistic, H.'s were either sharp or antagonistic, the latter greatly preponderating. Fig. 11, types O to W, examples selected (not, however, in consecutive order) from all the series, shows his characteristic variations in form. The forms which appear most commonly in H.'s records are those of types S and U (183/280 cases). These forms have been classed as "slight antagonistic reactions."

Comparison of the different forms of movement with the character of the attention as shown by the introspections, again brings out the point that there is no development of a preponderating reaction form with practice. There are, for instance, more sharp than antagonistic reactions in series I, X and XII. In series I, H. was learning to use the machine and his attention was much more on the movement and finger than on the stimulus. In series X he shows a marked tendency to direct his attention

TABLE IV.—*Qualitative summary. Reactor H.*

Key *Series No.*	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*	*XIII*	*XIV*	*Total*	
Rise before warning	2	1	2		1	2	1	1		1	3	3	1	1	19	
Fall before warning	7	6	7	9	10	6	7	8	14	6	6	7	3	7	103	
Level before warning	8	7	6	7	2	10	6	9	4	9	7	4	7	9	95	
Wavy before warning	4	6	5	4	7	2	6	2	2	4	3	5	9	3	62	
Change at warning	15	14	9	12	16	10	16	15	11	10	14	15	12	3	172	
No change at warning	6	5	10	8	3	10	4	5	9	10	6	4	8	17	105	
Reacted to warning		1	1		1										3	
Marked rise after warning															0	
Medium rise after warning												2			2	15
Slight rise after warning	1	1		1		1	2	2		3	1		1		13	
Marked fall after warning															0	
Medium fall after warning			1	3	2	2			3	1	2		3		17	82
Slight fall after warning	5	4	9	3	5	9	7	6	4	4	1	1	1	6	65	
Level after warning	9	8	5	12	9	5	6	10	12	11	13	4		10	124	
Wavy after warning	6	7	4	2	4	3	5	3	2	2	2	12	15	4	71	
Marked rise towards end							2								2	
Medium rise towards end		2		3	1		1	1			4	2			14	40
Slight rise towards end	2	2	1	1	2		1	2	3	5	1	2		2	24	
Marked fall towards end								1			2	1			4	
Medium fall towards end	2	2	2	2	2		2	2	2	1	4	1	1	6	29	76
Slight fall towards end		1	4		4	5	9	5	5	3	2	3		2	43	
Level at end	17	12		14	7	14	5	8	8	10	6	5	2	6	114	
Wavy at end			11		2	1		1			1	6	17	4	43	
Reacted before stimulus										1		1		2	4	
Sharp reaction	11	2	4	1	7	4	8	1	2	12	4	9	3		68	
Gradual reaction														1	1	
Slight antagonistic reaction	9	15	15	19	11	16	9	18	15	8	13	8	12	15	183	
Marked antagonistic reaction	1	1	1								2		4	3	12	199
Gradual antagonistic reaction		2					1					1			4	
Double reaction					1		2	1	1			1	1	1	8	
Number of reactions in series	21	20	20	20	20	20	20	20	20	20	20	19	20	20	280	

to the movement rather than to the stimulus. In series XII, H. was tired and distracted by an examination. Like reactor M., therefore, H. assumed at the start a very definite form of reaction movement and maintained it in the majority of reactions to the end of the fourteen series, departures from it being due, introspectively, to changes in the direction and amount of the attention.

The sharp form of final reaction movement is accompanied by two types of introspection. Either, "fast, afraid of reacting too soon," or "medium slow, wavering attention." These two types of introspection indicate that the sharp reactions occurred when the reactor's attention was turned towards the finger or movement, or was generally lowered. The slight antagonistic reactions occurred when the conditions were the most normal. At such times H. stated that his attention was good and turned toward the expected stimulus. The three most marked antagonistic forms, on the other hand, occurred when the reactor's attention was distracted by some other thoughts. Examples of this are found in series III, No. 8: "Bad attention, thinking of my failure to get here yesterday"; series XI, No. 16: "Slow, thinking of preceding reactions"; series XIII, No. 2: "Signal came before I was ready." The four gradual antagonistic reactions also occurred at times of distraction. Two were reactions before the stimulus. In the others H. states, "Mind on warning; hard to hear warning." Examples of these reactions are shown in Fig. 11, types Z and A′. The double reactions, as in the case of M., were caused by the attempt on the part of the reactor to check a reaction before the stimulus. In both cases H. was conscious of this form of movement since he stated after each, "Started and stopped." An example of the double reaction is shown in Fig. 11, type Y.

Such comparisons show more emphatically a definite relation between the form of movement and the character of the attention. Marked departures from the normal type of attention were accompanied by marked departures from the normal form of movement. The same relation holds true in the period just before the final movement made in response to the stimulus.

Only two cases of a marked rise towards the end appear. These two are followed by the double reaction movements which we have just examined.

The fourteen cases of a medium rise towards the end are accompanied by introspections which show distraction or a lowered attention. For example, series XI, No. 17: "Simply could not concentrate my attention"; series XII, No. 15: "Poor attention, thinking of examination."

Another characteristic appears in H.'s data showing him in marked contrast to M. In the period before the warning, H. exhibits a strong tendency to increase the pressure. The warning signal often emphasizes this. The increase is interesting in the light of a statement made by H. at a later time, which will also be used in another connection. He said that he felt the need of a firm foundation from which to start the reaction movement,—the increase in pressure seemed to be an attempt to "strike bottom." M., whose pressure lessened, apparently felt no such need. In general, too, the warning signal introduced less change in the character of H.'s pressure than in that of M.

Where does reactor H. belong judged by the criteria for sensory and motor reactions? His reaction times are much longer than those of M. (60σ longer), but they are still short compared with the 200-220σ established by Lange for sensory reactions. The mean variations are also somewhat larger than those of M. In themselves the reaction times and the mean variations would not definitely classify H. as either sensory or motor. Considered in conjunction with the almost complete absence of premature reactions they offer presumptive evidence, however, that he was of the sensory type. Only four reactions before the stimulus occur. The introspections show that one of these occurred when the reactor's mind was wandering, and the other three when the attention was turned away from the stimulus towards the finger. Several trials were made to test the effect of long warning intervals given at unexpected times. These reactions were not included in the normal results and occurred at the end of the different series. In no case did H. react before the stimulus after one of these long intervals. He stated that his

muscular preparation for the reaction movement increased, but that his attention turned more and more intently towards the delayed stimulus.

His further introspections give clear proof that H. was of the sensory type. He made the following general statement in regard to his attitude and attention during the majority of reactions: "I sit waiting for the warning signal with my attention wholly in that direction. After the warning comes I seem to tighten up my muscles all over in preparation for the coming reaction and my attention turns towards the stimulus, waiting for it to sound. Sometimes the increased tightening of the muscles draws my attention towards my finger, causing my attention to fluctuate back and forth between my finger and the sound. I always hear the stimulus, however, and would not react until it sounds." Only five times out of the 280 does there appear any introspection that would indicate attention turned toward the finger or the movement. There are 25 introspections which record lowered attention or distraction. The remainder (250) state that the attention was "good" or "normal," i. e., on the expected stimulus.

These introspections clearly place H. among the sensory reactors; and like reactor M., H. assumed his type of reaction naturally without any instructions, thus bringing him also under Baldwin's classification of natural types. This fact is of particular interest because, with this natural type of attention and reaction went also a definite form of reaction movement,—both entirely different from the natural type of attention and the form of movement assumed by M. Whereas M. decreased the pressure from the warning signal to the end of the record and responded to the stimulus by a simple sharp rise, H. maintained a constant pressure or increased the pressure from the warning signal on and responded to the stimulus, in the majority of cases, with an antagonistic reaction. Any marked changes, furthermore, in the form of movement could be correlated with changes in attention, as in the case of M.

This antagonistic form of movement has a marked effect on the length of the total reaction time. As we have seen, it would

be necessary to subtract 25σ from the reaction time of H. to obtain the time between stimulus and the real beginning of the reaction movement, i. e. the beginning of the antagonistic phase. So far as we have gone it would not be possible for us to say, however, that the antagonistic form of movement would *always* occur with the sensory type of attention, and the simple sharp form with the motor type. These forms might be purely individual. This point needs further investigation and a discussion of the facts will be postponed until the results of other reactors have been described.

Special Series.—Three series of reactions (thirty in all) were taken in which H. was directed to center all his attention on the coming stimulus and to let the movement take care of itself. The average time is 147.1σ. This is 17.6σ longer than the average time of the regular series. The mean variation is lower than that of the regular series by 3.4. The average reaction time brings H. nearer the traditional sensory type. H. stated that this form of reaction seemed natural to him, and that he had not thought of his finger at all, or of the movement, in the last two of these series. In the pressure curves the same characteristics appear (but in greater degree), which appeared in those of the regular series. As in the regular series the cases are about equally divided between a downward pressure before the warning and a steady pressure. There are relatively more cases of change in pressure at the warning. There are only two cases of a rise after the warning, neither being of the marked type. There is a much greater proportion of increases in pressure after the warning, 15/30, than in the regular series. The remaining cases are level or wavy. There are only two cases of a rise towards the end, neither of them marked, but still more cases, relatively, of increase in pressure, 20/30, than in the regular series. The final reaction movement in almost every case is of the antagonistic type, 25/30. Eighteen of these are of the slight antagonistic type, shown in Fig. 11, types S, T and U, and the remaining seven of the marked types, V and W. There is only one double reaction, which occurred when the attention shifted slightly to the movement. In the series in which the attention of the reactor

was most strongly centered on the coming stimulus, more antagonistic reactions of the marked type than of the slight type appear. At the end of this series the reactor stated, "Absolutely no attention paid to finger." We seem justified in the assumption that this series is of a more uniform sensory type. In the regular series this uniformity was interfered with by fluctuating attention. By distributing the forms of movement in the first *regular* series under the types of attention in which these movements occurred, we found the form of movement most regularly accompanying the sensory type of attention to be a downward pressure preceding the reaction, followed by the antagonistic movement in the reaction itself. In this special sensory series we find these characteristics more marked.

Three series of motor type were attempted in connection with these special sensory series. The reactor did not succeed in establishing the motor type of attention. He stated that he simply "fixed his attention upon his finger and waited for the stimulus," which seemed rather a paradox. The records show an increase in time of 3σ over that of the special sensory series. This fact in itself, aside from the introspections, indicates that there was very little difference in the character of the two series. The mean variation is very much increased, 21.3, showing that the attempt to fix the attention for a motor series proved a distraction. We find, in fact, the pressure characteristics of the sensory series appearing in a more marked degree. There are no cases of rise after the warning or towards the end and 21/28 cases of a fall towards the end. All but one (27/28) of the reactions are of the antagonistic type. These are distributed as follows: 21/27 slight antagonistic reactions, 5/27 marked antagonistic reactions, 1/27 gradual antagonistic reactions.

H. was carefully questioned as to his attitude in these reactions. It was found that he did not interpret "attention on the movement" or "attention on the finger" to mean a preparation for a quick upward movement. He fastened his attention on the finger and was more concerned than ever in holding it down upon the key. A good example of this, in a single reaction, is as follows: the reactor stated, "Medium time; attention on finger." The

time was really very slow, 225σ. As to the form of the movement, there is a very marked fall in the line after the warning, meaning a marked increase in the pressure. This is followed by a very marked antagonistic reaction. H. stated, furthermore, that he always waited for the stimulus in these series. No cases of reaction before the stimulus occur. A special trial was made at the end of one series to see if the reactor could be made to react before the stimulus. The interval between the warning and the stimulus was increased to 3.2 seconds. H., however, reacted in normal time (140σ) and did not seem to be at all disturbed by the delay. These attempted motor series seem, then, to be sensory, with the additional complication of increased attention to holding the finger on the key. H.'s whole attitude was so strongly sensory that a very long practice series would have been necessary to develop the motor type of attention. These series then, do not serve as a check on the sensory series. They show, however, how strong the tendency in one direction can become and how difficult it would be ever to get a motor series with such a reactor. This explains very well what the Leipzig experimenters call absence of "Anlage."

One series of discrimination reactions was taken with H. One electric hammer was placed at the right of the reactor, with a second at his left, both behind the screen. By means of a multiple switch either of these hammers could be thrown into the reaction circuit. H. was instructed to react to the sound on his right and not to react to the sound on the left. The average time was 247.1σ. The mean variation was large, 51.3. The form of movement corresponds to that made in the sensory series. Of the fourteen reactions to the stimulus on the right, ten show a change at the warning; ten increased pressure after the warning; ten show a strongly increased pressure towards the end. There are no cases of a decrease in pressure during the period between warning and stimulus. The final reaction movement is of the antagonistic type in all but two of the reactions. These antagonistic reactions are more marked than any of the forms shown in the earlier series; the sharp downward trend of the curve often beginning, too, before the warning signal. There is one double

reaction, the first reaction taken. The reason for this is evident from the introspections. The reactor managed to see the spring on the electric hammer move before the sound came. This caused the preliminary start which was checked until the stimulus sounded. The hammer was then moved completely behind the curtain and this distraction did not occur again. The character of the pressure when the stimulus at the left sounded is very interesting. There is the same gradual increase in the pressure up to the point at which the stimulus occurs. Here the pressure becomes still greater, causing a trough in the curve about 200σ in length, after which the pressure is steady, or in some cases decreased until the motor is stopped. This involuntary downward start was noticed, when it became marked, by the reactor and was recorded by him in the introspections.

The data thus far seem to show, then, that when the attention is concerned with the coming stimulus, there occurs an increase in pressure during the period preceding the reaction (reactor H.). When the attention is concerned with the movement to be made (reactor M.), there occurs a decrease in pressure during the same period. We will leave the discussion of reasons until later.

A series of twenty reactions was taken with H. on a regular electric break key. He was allowed to react in his normal way. The time was increased to 152.1σ. The mean variation was lower than the average for the regular series, 15.7. The reactor said after his first trial, "This feels more like it." At the end of the series he stated that this key seemed to require more pressure than the spring key. This fact was a recommendation in itself to him. He felt, as already stated, the need of a firm foundation from which to start. The spring key did not furnish it. He believed that all his times were much faster with the electric break key than with the spring. H. was then tested with a large tambour. The times were increased still more. The average for the series of 20 reactions was 155.9σ. The mean variation was also increased, 24.1. The form of the movement was the same as with the spring. There was a marked downward pressure before the stimulus and a more marked antagonistic reaction

movement. H. did not like this type of apparatus at all; it seemed like "trying to start to run from a bed of sand." The rubber of the tambour did not give him even as solid a basis as the spring.

These statements in regard to the different forms of reaction apparatus are interesting in view of the antagonistic tendency exhibited by this reactor. Whereas M. found the spring key most suited to the preparatory rise in the period preceding the reaction movement, H. found that the electric key gave a greater feeling of security in view of his tendency to press down in the period preceding the reaction so as to get a solid basis from which to start the upward movement. The electric key, however, increased the reaction time, doubtless because the rigidity of such a key did not allow free play of the antagonistic tendency but rather interfered with it, acting not only as a check on the antagonistic movement but upon the subsequent rise. The fact that this key felt most secure doubtless accounts for the feeling of the reactor that he was making faster reactions.

After all the test experiments with spring, tambour, and key, H. was told about the antagonistic tendency and asked if he had noticed it and if he knew of any other facts in his experience which would account for it and for his sensory type of attention. He said he had noticed this final downward push only a few times. This accords with the more detailed introspections, where we find only three such statements in the regular series. He stated that such a movement seemed to accord with his general nervous habit of suddenly tightening any muscles he was about to use before the actual movement was made. In his undergraduate days he had been a hundred-yard-dash man. So far as he could remember he had never "jumped the gun." He always gave a preliminary dig with his feet and crouched slightly as if to spring, the instant before the signal came. He said that this preliminary "start" had often caused the men at his side to leave their marks before the signal but that he had never done so himself.

Summary.—We have shown:

First, that the type of pressure up to the stimulus, and the type of the final reaction movement shown by reactor H. in the regular series appear more often and to a more marked degree in the special sensory series.

Second, that it was not possible for reactor H. to establish the motor type of attention in the three series tried.

Third, that whenever the attention was directed away from a fast final movement, the pressure in the period preceding the reaction movement tended to increase.

Fourth, that there is some reason to believe, in view of these facts, that the antagonistic movement appears more often in the sensory type of reaction (reactor H. compared with M.).

Fifth, that the form of key has a marked influence on the reaction time.

Reactor E.

Having dealt thus fully with the two previous reactors, in order to show the methods of procedure and of analysis of results, it will not be necessary to go into such detail with the remaining reactors.

Both M. and H. exhibited definite forms of movement which could be correlated with the reaction times. But more than this, these reaction times and forms of movement accompanied definite types of attention, utilized by earlier investigators in their classification of reaction types. With E. we come to a reactor whose movement records did not show uniform characteristics throughout and whose average reaction times were scattered from 244σ to 105σ. At first sight it would seem impossible to harmonize such results with those of the previous reactors. A careful study showed this, however, to be possible.

E. had had no training in reaction experiments; the ordinary instructions to raise the finger on hearing the stimulus were given him at the beginning of the series. A total of 202 reactions was taken in these uninstructed series. The average corrected time for the ten series (Table V) is 155.9σ with a mean variation of 30. The average corrected time of series I is long-244σ with a M. V. of 50. The times decrease regularly and the M. V.'s fairly regularly to the ninth series (time 105σ; M. V. 24). The time goes up again slightly in the tenth to 110σ with a M. V. of 18.

TABLE V.—*Summary of average times and mean variations. Reactor E.*

		Chronoscope		Corrected		Movement began	
No. of Series	*Warning time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
I	2.3	263	53	244	50	238	50.7
II	1.6	227.5	59.5	204	54.8	198	51.4
III	2.2	211	21.6	190	29.3	178	26.3
IV	2.3	185	32	175	29.2	153.2	29
V	2.3	185.9	33.4	156.7	28.5	149.7	21.2
VI	2.2	166	28.4	141.9	34.1	118.1	38.9
VII	2.2	142.5	19.6	120.6	17.6	119.6	17.9
VIII	2.1	137	20.2	111.5	22.2	110.8	21.4
IX	2.0	137	20.1	105.3	24.2	96.4	29.7
X	2.3	139.5	15.6	110.7	18.1	105.2	25
Averages .	2.15	179.34	30.34	155.97	30.79	147.7	31.15

Such a regular decrease in the average reaction times and mean variations indicates that we are dealing with a marked practice series. In order to show this more clearly, the times were distributed according to their frequency (Fig. 12, curve A).

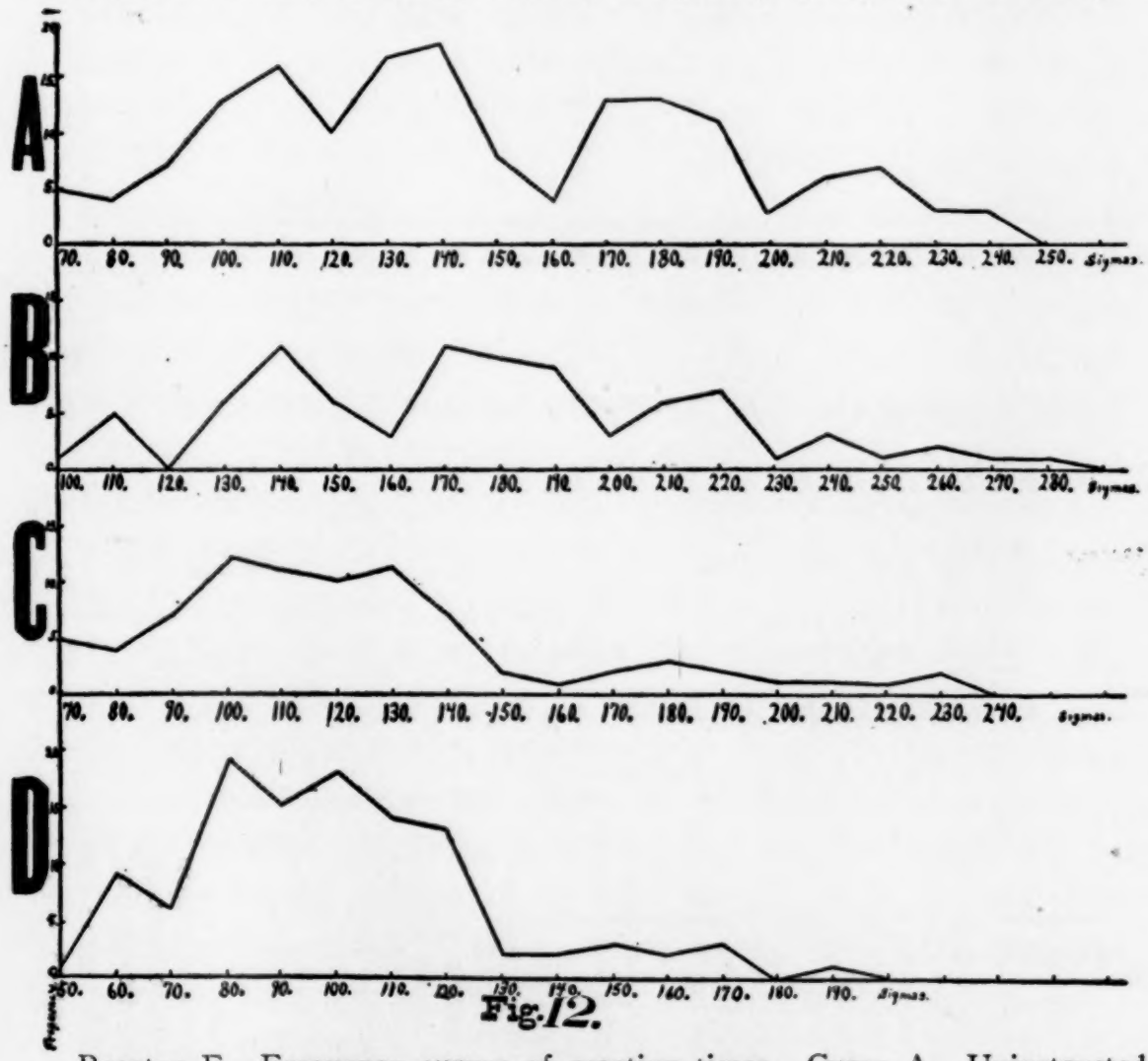


Fig. 12.

Reactor E.—Frequency curves of reaction times. Curve A. Uninstructed series. Curve B. First half of uninstructed series. Curve C. second half of uninstructed series. Curve D. motor series.

TABLE VI.—*Qualitative data sheet. Reactor E.*

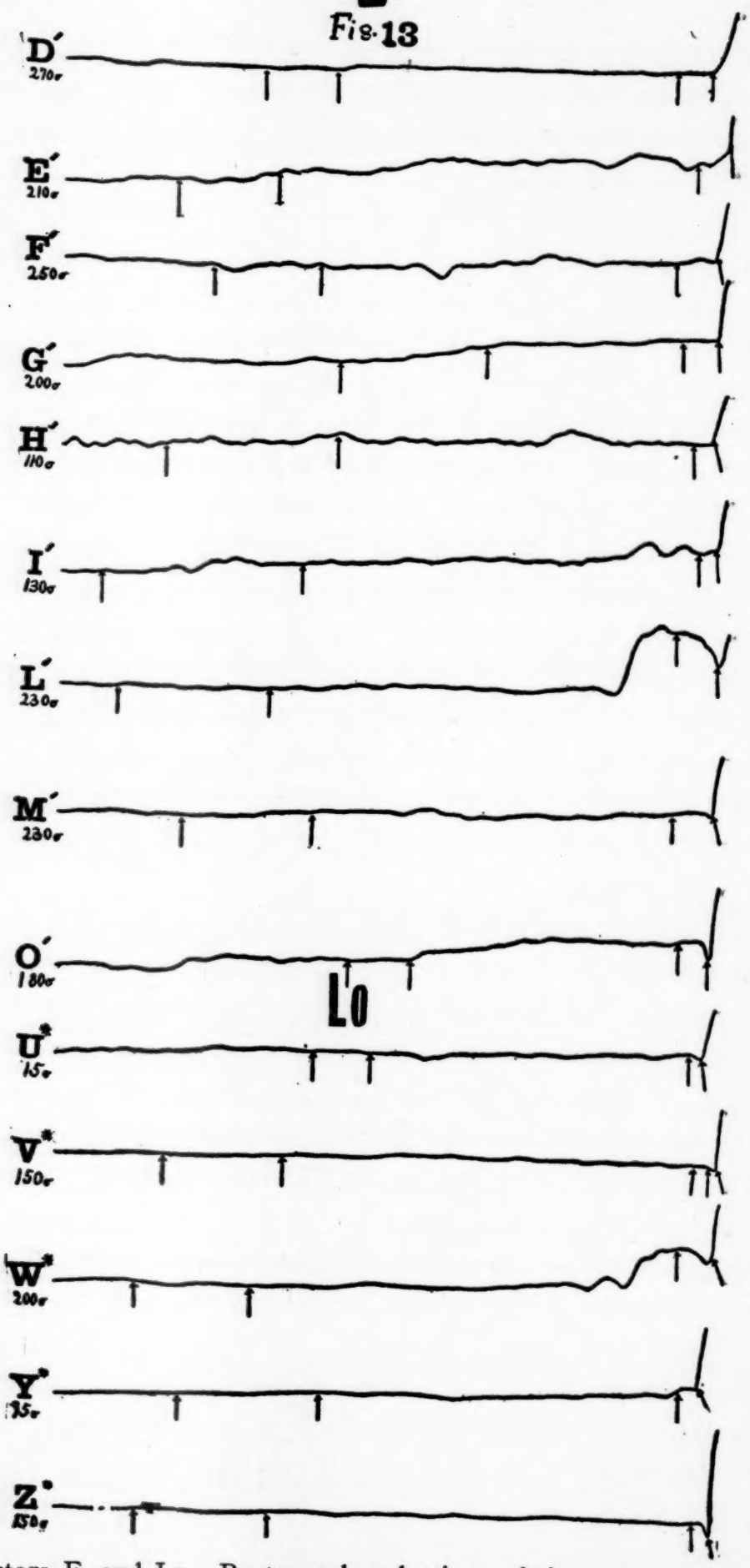
Key — *Series No*	*Uninstructed Series*											*Total*	*Motor Series*						*Total*	*Total*
	I	*II*	*III*	*IV*	*V*	*Total I-V*	*VI*	*VII*	*VIII*	*IX*	*X*	*VI-X*	*XI*	*XII*	*XIII*	*XIV*	*XV*	*XVI*	*XI-XVI*	*I-X*
Rise before warning.....	1	1	1		2	5			1	4	3	8	2	2	1				5	13
Fall before warning.....	1	5		6	2	14		3	3	4	2	12	1		8				9	26
Level before warning	14	10	9	9	14	56	19	9	14	10	13	65	10	8	9	2	9	4	42	121
Wavy before warning....	4	7	10	4	2	27	1	8	2	2	2	15	7	3	2	19	11	16	58	42
Change at warning.....	17	19	16	15	13	80	14	11	13	14	18	70	16	12	17	19	15	13	92	150
No change at warning....	2	3	4	4	6	19	6	9	7	6	2	30	4	1	3	2	4	7	21	49
Reacted to warning	1					1						0							0	1
Marked rise after warning	1	1				2		1				1							0	3
Medium rise after warning	5	7	2		1	15 } 40		1		2	6	9 } 40	2		5		3		10 } 34	24 } 80
Slight rise after warning..	9	6	3	2	3	23	6	7	3	6	8	30	10	6	4		4		24	53
Marked fall after warning						0						0							0	0
Medium fall after warning				4		4 } 8						0 } 7							0 } 2	4 } 15
Slight fall after warning..				3	1	4	3		2		2	7		1	1				2	11
Level after warning.....	2	4	4	8	7	25	10	10	5	7		32	1	4	3		4	1	13	57
Wavy after warning.....	2	4	11	2	8	27	1	1	10	5	4	21	7	2	7	21	9	19	65	48
Marked rise towards end	1				3	4		1	1	5	2	9			1	4		1	6	13
Medium rise towards end	7	5	4	1	3	20 } 47	2	6	3		5	16 } 44	1		6	3	1	3	14 } 43	36 } 91
Slight rise towards end..	3	6	4	3	7	23	4	3	6	2	4	19	5	1	6		7	4	23	42
Marked fall towards end..		1		1		2				1		1				5		1	6	3
Medium fall towards end	2	2	2	1	1	8 } 21	2		2	2		6 } 19	2	2	1	2	1	2	10 } 22	14 } 40
Slight fall towards end...		2		9		11	3	5		2	2	12	1	1	1		1	2	6	23
Level towards end.....	6	5	5	3	6	25	9	5	8	7	5	34	6	6	4	2	5	7	30	59
Wavy towards end.....			5			5					2	2	5	3	1	4	5		18	7
Reacted before stimulus..						0						0			1	2	1		4	0
Sharp reaction	6	11	3	4	9	33	8	13	19	12	18	70	16	6	15	7	18	16	78	103
Gradual reaction	10	5	11	1	10	37	6	6		3	1	16	3	7	5	11	1	4	31	53
Slight antagonistic reaction		4	1	8	1	14	4	1	1	2		8				1			1	22
Marked antagonistic reaction	3	2	5	4		14 } 29	1					1 } 12							0 } 2	15 } 41
Gradual antagonistic reaction				1		1				2	1	3				1			1	4
Double reaction.....						0	1			1		2	1			1	1		3	2
Reactions in series.....	20	23	20	19	20	102	20	20	20	20	20	100	20	13	20	20	20	20	114	202

This is roughly a double frequency curve. The most frequent of the shorter times lie between 110σ and 170σ, and of the longer times between 170σ and 190σ. So much for the uninstructed series as a whole.

Dividing it into two parts, series I to V, and VI to X, and distributing the reaction times in these two half series according to their frequency, we get curve B, Fig. 12, for series I to V, and curve C for series VI to X. Curve B shows a very wide distribution of times with no grouping in any one region. Curve C gives a marked grouping of the times in the region between 100σ and 130σ. These curves, together with the general decrease of the average times, show clearly that reactor E assumed the short reaction times in the course of practice.

Reactor E.'s pressure curve (Fig. 13) is much more irregular than any thus far considered. Such irregular records as those shown in types E′, F′ or I′ are very typical. There are very few records of type H′, where the smaller waves due to hand trembling occur, and these are almost entirely in the last two series, in which the reactor was tired and nervous. The large inequalities we found to be accounted for by the shoulder and arm movements of the reactor.

In Table VI a summary is given of the characteristic parts of the pressure curves for each half separately of the total uninstructed series. We find in both halves a very remarkable agreement in the characteristics of the curves up to the final reaction movement. The most prominent are as follows: The pressure is steady to the warning signal. When the warning occurs there is usually a marked rise in the curve. This amounts in some cases almost to a partial reaction to the warning. Very seldom does the warning cause an increase in pressure. There is usually a decrease in pressure in the period after the warning signal, with fewer cases of a steady pressure, and very few of increased pressure. There are many cases of decrease in the pressure towards the end, in preparation for the reaction, more of the marked decreases occurring in the second than in the first half of the ten series. There are relatively few cases, towards the end, of increase in the pressure with somewhat more of a



Reactors E, and Lo.—Pantograph reductions of the pressure curves.

constant pressure. There are many cases of waviness in both the period before the warning and the period immediately after the warning, and but few cases of waviness at the end.

When we turn to the final reaction movement there is a marked change in type between the two halves of this uninstructed series. In the first half the reactions are almost evenly divided between those of the sharp type G′, Fig. 13 (32/102); the gradual type D′ (37/102); and the antagonistic types M′ and O′ (29/102). There are no reactions of the double type. In the second half of the series, 70/100 are of the sharp type G′; 16/100 of the gradual type D′; 12/100 are antagonistic in type (M′ and O′), and 2/100 are of the double type L′.

We see, then, that a change in the form of the final reaction movement accompanies the change from longer to shorter average times. With the longer average times occurred relatively more antagonistic and fewer sharp reactions, while with the shorter times, almost all reactions were of the sharp, and very few of the antagonistic type. This agrees with our conclusions in regard to the earlier reactors.

What was the character of E.'s attention throughout this uninstructed series? The frequency curves B and C, Fig. 12, have shown that E. developed the short reaction times and low mean variations with practice. No wrong or premature reactions occurred in either half of the series. Nothing was said to the reactor about the distinction between the sensory and motor types of attention. At the end of series IV, he stated of his own accord that he thought his attention had been on the signal. At the end of series V, he said his attention seemed to have been divided very equally between the signal and the finger. At the close of series VII, he stated, "It seemed to me that the times were faster than usual." Such a statement appears to indicate greater interest in the speed of the movement. In series IX, the reactor states, for reactions Nos. 3 and 4, "Slow; thinking of signal." Such a statement indicates that this form of attention was then a distraction. On the other hand there are many introspections in regard to the movement of the hand or arm which show clearly the direction of the attention at least during a portion of the

reaction period. For example, in series IX, reaction No. 6, the reactor says, "Medium fast; marked downward pressure." We find that this is a correct introspection of the movement. Or again, in the same series, reaction No. 9, he states, "Medium fast; pressure in jerks."

In almost every case in series VII to IX, E. makes some statement as to the character of the pressure, such as "steady," "unsteady," "wavy pressure at end," etc. Such statements leave little room for doubt, when taken in connection with the times, that E. was a reactor of the motor type by the time series VII or VIII had been reached. At the beginning of series X, E. was told of the different types of attention and asked to introspect on this point carefully. This he did and at the end stated that he thought his attention went more naturally to the movement than to the stimulus. Such a statement taken by itself might prove of little value, since the effort to notice the character of the attention might have produced an abnormal attitude. It furnishes added proof of the motor type of attention, however, when taken with the other factors.

These introspections, with the frequency curves, show clearly that E. started with a sensory type of attention and developed the motor type through practice. The forms of the final reaction movements in the first half of the uninstructed series I-V, more nearly correspond, furthermore, to those found with the sensory type of attention in the case of reactor H. The forms of final movement in the last half of the series, VI-X, correspond to those found in the motor series of reactor M.

Those phases of the curves *preceding the final reaction movement* did not, however, exhibit unambiguously similar correspondences to the curves of M. and H. With them we found that a rise after the warning and towards the end occurred in the motor type of attention, and that a fall after the warning and towards the end was more often associated with the sensory type of attention. With reactor E. we have seen, however, that there is little obvious change in the character of the pressure in these parts of the record, as the reaction changes from the sensory to the motor type. The reason for this can be seen by an inspection

of the curves themselves. The curves are so irregular and there are so many waves, both of the small hand waves and the large arm waves, that these tend to conceal any definite tendency to decrease or increase the pressure.

The cases of observed increase in pressure after the warning were therefore distributed according to the character of the attention stated in the introspections, in order to get, more in detail, the correlations between movement-form and attention. In the first half of the uninstructed series, eight cases of increased pressure after the warning occur, seven of these being in series IV. At the end of this fourth series E. stated of his own accord that his attention had been on the stimulus. In the second half of the uninstructed series only seven cases of increase in pressure, very slight, occur, after the warning. The records show that these are due to chance arm movements rather than to a definite tendency to increase the pressure in this period. In a motor series (XI-XVI, to be considered later) only two cases of a slight increase of pressure after the warning are found. These also are due to the larger chance arm movements. Of the increased pressures towards the end, in the first half of the uninstructed series, over half occur in series IV, spoken of by E. as accompanying attention to stimulus. All but one of the remaining occur in the first three series before a definite type of attention had been developed. In the second half of the series there is only one case of a marked increase in pressure towards the end. This is in series IX, and preceded a gradual antagonistic reaction, noticed by the reactor, since he states in the introspections, "Marked downward pressure." There are six cases of a medium increase in pressure towards the end in the second half of the series. These are due to unsteady pressure rather than to a definite increase.

Although, then, E.'s curves for the periods preceding the final reaction movement do not vary much on the average as his type of reaction develops from sensory to motor, it appears that specific cases of increased pressure may be, in general, correlated with a non-motor type of attention. Coming now to the final reaction movement itself which, as we have seen, did markedly change with the advent of the motor type, the number of sharp

reactions increasing and that of antagonistic reactions decreasing, we get the following more detailed analysis. Fourteen *slight* antagonistic reactions occur in the first half of the uninstructed series. Four of these occur in series II, one in series III, eight in series IV (which we have seen was regarded by E. as accompanying attention to the stimulus), and one in series V. Fourteen *marked* antagonistic reactions occur, furthermore, in this first half of the series, distributed as follows: Three in series I, two in series II, five in series III, and four in series IV. There are no marked antagonistic reactions in series V. One of the two in series II is interesting in relation to the introspection. The time was very long, 355σ. The reactor realized this and made a great effort to react quickly. This increased effort resulted in the final antagonistic movement.

We have seen that the attention had not reached the motor type in this first half of the uninstructed series. In the second half eight slight antagonistic reactions occur, distributed as follows: four in series VI, one in series VII, one in series VIII and two in series IX. Of these slight antagonistic reactions, two occurred when E. was distracted by an outside influence. In one case E. records, "Making a greater effort." In another case he states, "Thinking of signal; slow." This was in series IX. The only other slight antagonistic reaction in series IX occurred because of an attempt to check a reaction before the stimulus. Only one marked antagonistic reaction occurred in the second half of the uninstructed series. This was in series VI. A man entered the room just as this reaction occurred, causing the reactor to give an involuntary start. E. stated that this did not cause a distraction, but the start shows in a most marked antagonistic reaction. As E.'s reaction type becomes definitely motor, the antagonistic reactions not only, then, become fewer, but are manifestly correlated with exceptional states of attention.

Two double reactions occur, furthermore, in the second half of the series, with none in the first half. A double reaction, as we have found with reactors M. and H., is associated with a strong tendency, of which the reactor is aware, to react before the stimulus. This appears in the motor type of attention. The

records show, finally, that in the first half of the series more than one-third of the reactions were of the gradual type. In the second half of this series the proportion of gradual reactions had dropped to less than one-sixth of the total, being replaced by sharp reactions.

Since E. seemed to have reached the limit of speed and since he had adopted a more or less definite type of attention, he was told at the end of series X to center his attention, in the remaining series, on the movement to be made. The next six series (XI-XVI) will be referred to, therefore, as the "motor series." At the outset the conscious effort to concentrate the attention in this way proved a slight distraction to the reactor, since the times and mean variations were temporarily raised. This distraction was only temporary, however, the effort not extending beyond series XI.

The average time for this motor series was 101σ, the mean variation 20 (Table VII). The time decreased regularly from 123σ in series XI to 83σ in series XIV. It increased slightly in series XV (98σ), since the reactor was tired and nervous, stating, "I found it hard to concentrate my attention during this series; all the times seemed longer than usual." The time of series XVI (94σ) offered, however, no similar introspective reasons. Distributing the times in these motor series according to their frequency, we have curve D, Fig. 12. This curve shows the motor type of reaction to a more marked degree than in the original uninstructed series. The most frequent times lie between 80σ and 120σ. This not only adds force to the earlier statement that the motor type of attention had been assumed in the later uninstructed series; it shows also the ease with which the reactor was able to carry out the instructions as to the motor type of attention. Two reactions before the stimulus occur, both due to anticipation of the signal by the reactor.

The same characteristics of form, found in the last half of the uninstructed series, appear in the motor series in a more marked degree (Table VI). There is little difference, however, in the character of pressure in the periods preceding the reaction, except that in the motor series there are but 2/114 cases of increased

TABLE VII.—*Summary of averages and mean variations. Motor series. Reactor E.*

		Chronoscope		Corrected		Movement began	
No. of Series	*Warning time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
XI	2.2	149	23.3	123.5	21.8	118.5	24.7
XII	2.2	136	17.39	112.8	13.5	112.8	13.5
XIII	2.0	121.8	24.2	96.4	20.8	96.4	20.8
XIV	1.7	115	28.1	83.4	28.5	78.9	32
XV	2.2	132.6	24.1	97.8	17.4	97.8	17.4
XVI	2.2	119.2	19.2	94.1	19.8	94.1	19.8
Averages	2.0	128.9	22.7	101.1	20.3	99.7	21.3

pressure after warning as against 7/100 cases in the former series. It is in the final reaction movement itself that the differences between the two series are most marked. Whereas the sharp type of reaction is characteristic to an equal degree of both, the number of gradual reactions in the motor series has increased to 31/114 over the 16/100 in the last half of the uninstructed series; and the number of antagonistic reactions has fallen from 12/100 in the latter to 2/114 in the motor series. Neither of these is marked. Both, furthermore, appeared introspectively as exceptions. For one E. stated, "unsteady pressure," the form of reaction doubtless resulting from an attempt to control the unsteadiness. In the other antagonistic reaction the attention wandered. Finally, for each of the three double reactions occurring in the motor series, E. stated, "Reacted too soon." Premature reactions are peculiarly characteristic of motor attention.

Summary. 1. E. developed the motor type of attention and progressively shorter reaction times in the course of a practice series.

2. With this change in attention went also a change in the form of the reaction movement.

3. The most marked feature of the change was the decrease in the number of antagonistic reactions and the corresponding increase in the number of sharp reactions.

4. In the motor series which followed the practice series there was a still greater decrease in the number of antagonistic reactions.

Reactor Lo.

Reactor Lo. was a student in the Graduate School with some previous training in reaction experiments. Both in the character of his attention and time of reaction he was the steadiest reactor thus far considered. There was, too, little unsteady movement of any sort.

In series I the ordinary instructions were given to lift the finger on hearing the stimulus. In the remaining series, II-VI, the reactor was instructed to fix his attention on the coming stimulus and to let the reaction movement take care of itself. Lo. was selected for this type of reaction since he stated that in his earlier tests he had found that type the most natural one. After the first series he stated that his attention had been entirely on the stimulus. This series, then, is included in the general sensory averages (Table VIII). There is a gradual decrease in the reaction time through the series,—from 159σ in the first series, to 121σ in the last. The average reaction time for the six series is 141σ. This is well above the lower limit for sensory times taken with the spring key. To show more definitely the change in reaction times through the series, these were distributed according to their frequency in the first and in the second halves respectively. Curves showing these results, together with a summary curve of the whole series, are given in Fig. 14. Curve A represents the distribution for series I-III and shows a very good concentration of the times about 140σ and 160σ respectively. There are, however, a few scattering times from 90σ to 240σ. Curve B, giving the frequency in series IV-VI, yields a remarkable concentration of the times in the region between 120σ and 140σ with almost no scattering. As we would expect from such a curve, the mean variations are low. The average mean variation for the whole series is only 14.8. In series IV it is only 8.

Such curves, together with the summary curve C, when taken with the average reaction time and the introspections indicate clearly a sensory series of a very regular character. Lo. simply gained greater speed by practice with this particular kind of apparatus, to which he was at first not accustomed. With this increase in speed went also an increase in regularity. The intro-

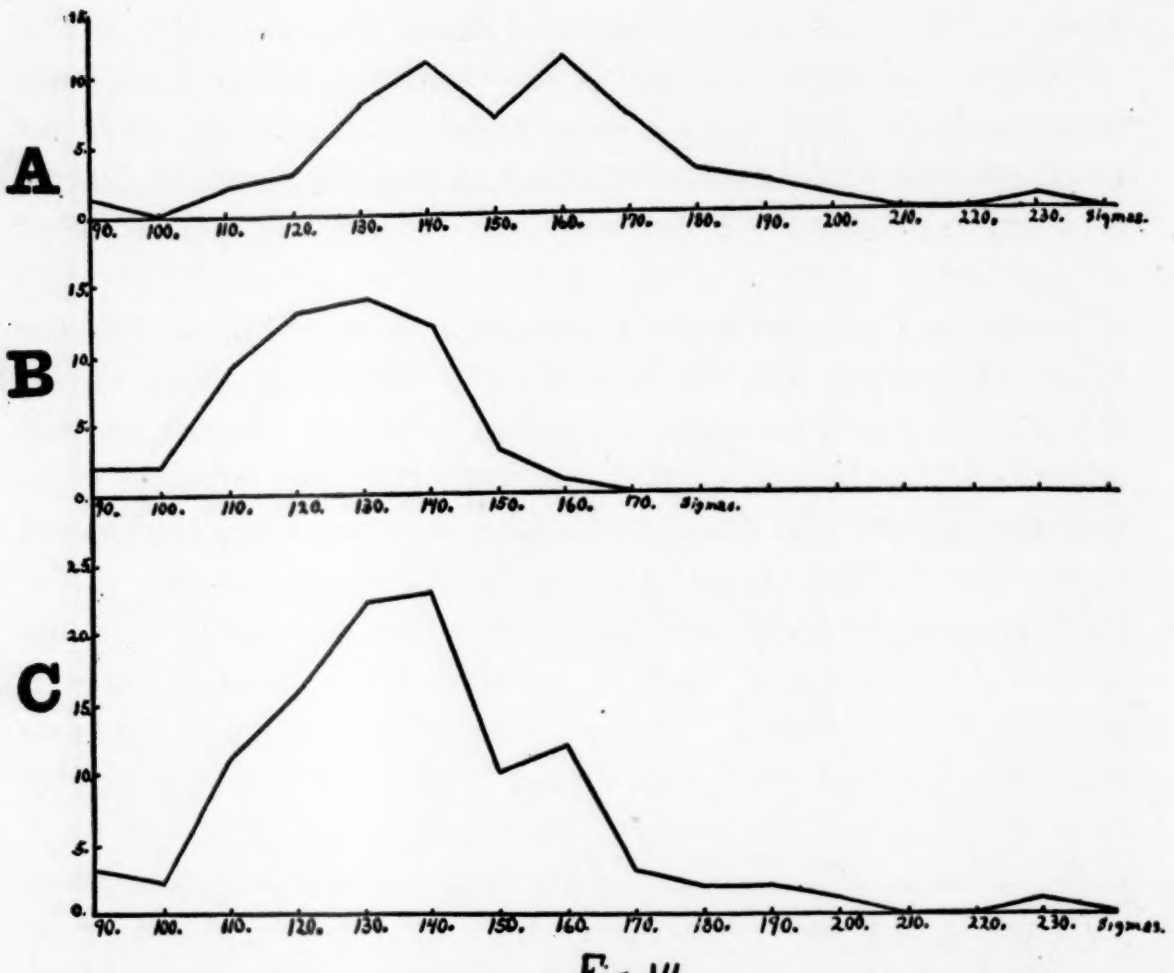


Fig. 14.

Reactor Lo.—Frequency curves of reaction times. Curve A. shows the frequency curve for the first half of the series. Curve B. shows the frequency curve for the second half of the series. Curve C. shows the frequency curve for the entire series.

TABLE VIII.—*Average times and mean variations. Reactor Lo.*

		Chronoscope		*Corrected*		*Movement began*	
No. of Series	*Warning time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
I	1.8	172.5	24.2	159.4	25.8	143.5	26.3
II	2.3	172	18.3	152.9	16.6	140.7	26.4
III	2.3	160.6	15.1	151	13.9	130.7	14.4
IV	2.0	144	9.6	132.5	8	116.1	12.2
V	2.1	140.9	11.1	128.8	11.2	120	10.9
VI	1.9	132.7	15.2	121.9	13.7	113.7	9.8
Averages	2.1	156.6	15.5	141.	14.8	127.4	16.6

spections show a remarkable lack of fluctuation in the attention. Out of ninety-six introspections only fourteen state a departure from the normal sensory type. Seven of these cases show that

the attention wavered between the stimulus and the movement. Seven state that the attention was entirely on the movement. Three of these cases of motor attention seemed to have caused a slight distraction, for Lo. states that the time seemed long. One could hardly expect a more regular series of the sensory type.

Qualitative Results.—The pressure curves of Lo.'s reactions are likewise the most regular and steady of any discussed so far (Fig. 13). Very few marked changes in direction of the curves appear at the critical points. The changes at the warning signal are for the most part of one kind, namely, a slight increase in the amount of pressure, which is maintained as a level line to the beginning of the final reaction. The final reaction movements are largely of the antagonistic type. The decrease in reaction time is accompanied by a slightly sharper type of slight antagonistic reaction. Curves U* and V* show this distinction, so far as the form of the movement is concerned; the times are in these cases reversed by other causes. No reactions of type U* appear after series I, all but four of the antagonistic reactions being of type V;* three of type Z.*

A detailed summary of the forms of movement in Lo.'s series appears in Table IX. Series I-III and IV-VI were summarized separately. There is almost complete identity between the forms of movement in these two series. A description taken from the total summary will, therefore, be sufficient. Over one-half of the records are level before the warning, the rest being divided between a rise, 19/117, and a fall, 30/117. In nearly two-thirds of the cases the pressure is changed at the warning signal. The pressure is level after the warning signal in two-thirds of the records. The remaining one-third is divided evenly between a slight rise and a slight fall. In over one-half of the records the pressure is level towards the end, but there are more cases of increase in the pressure, 30/117, than of decrease, 13/117; there are a few cases of waviness, 11/117. In no case did a reaction before the stimulus occur. This we would expect in a sensory series of this uniform type. In nearly two-thirds of the records the final reaction movements were of the slight antagonistic type (V,* Fig. 13). About one-third were sharp upward movements

TABLE IX.—*Summary of the forms of movement. Reactor Lo.*

Key — *Series No.*	*I*	*II*	*III*	*Total I-III*		*IV*	*V*	*VI*	—	*Total IV-VI*		*Total I-VI*	
Rise before warning	3	2	4	9		3	5	2		10		19	
Fall before warning	2	5	5	12		7	6	5		18		30	
Level before warning	12	13	8	33		9	8	12		29		62	
Wavy before warning	3		2	5		1				1		6	
Change at warning	13	9	11	33		14	14	9		37		70	
No change at warning	7	11	8	26		6	5	10		21		47	
Reacted to warning				0						0		0	
Marked rise after warning				0						0		0	
Medium rise after warning				0	8					0	7	0	15
Slight rise after warning	3		5	8		3	4			7		15	
Marked fall after warning				0						0		0	
Medium fall after warning	1			1	9		2	2		4	7	5	16
Slight fall after warning	3	2	3	8		1	2			3		11	
Level after warning	12	17	9	38		15	9	17		41		79	
Wavy after warning	2	1	2	5		1	2			3		8	
Marked rise towards end				0						0		0	
Medium rise towards end				0	5					0	8	0	13
Slight rise towards end	3	1	1	5		4	3	1		8		13	
Marked fall towards end				0			2			2		2	
Medium fall towards end		2	2	4	15	2	2	3		7	15	11	30
Slight fall towards end	4	5	2	11		3	1	2		6		17	
Level towards end	10	12	14	36		8	8	11		27		63	
Wavy towards end	3			3		3	3	2		8		11	
Sharp reaction				0						0		0	
Sharp reaction	9	10	3	22		3	9	9		21		43	
Gradual reaction	1			1						0		1	
Slight antagonistic reaction	10	10	14	34		16	8	9		33		67	
Marked antagonistic reaction			2	2	36	1				1	35	3	71
Gradual antagonistic reaction				0			1			1		1	
Double reaction				0			1	1		2		2	
Number of reactions in series	20	20	19	59		20	10	10		58		117	

(type Y*). Of the rest, three were of the marked antagonistic type Z,* one of the gradual antagonistic and two were double reactions. One of these is shown in type W.*

We may now consider, first, under what conditions of attention the more unusual forms of movement occur, and second, what forms of movement accompany the unusual types of attention, provided all of these are not included in the first distribution. There are eleven records which show waves towards the end. These indicate a tightening of the muscles in anticipation of the reaction movement. Such waves, we have found with the other reactors, appear more naturally with the motor type of attention. Of these, one was caused by a distraction, Lo. stating that he was watching the movement of his finger on the key. Five others occurred at times when the attention was divided between stimulus and finger. The remaining five occurred at times of ordinary sensory atention. Of the two double reactions, one occurred as we have seen, type W*, in a moment of distraction and the other in one of divided attention. Of the three marked antagonistic reactions, one occurred when the reactor's attention was on his finger and one during distraction (seeing the operator's movements). In the third marked antagonistic reaction the reactor stated, "Sensory; slow." This reaction was not slower than the average, but the antagonistic phase was longer. The only gradual antagonistic reaction in the entire series occurred when the reactor was asked to think about his breathing. It is interesting to notice that, though the attention was almost entirely withdrawn from the experiment and the reaction time increased to 350σ, yet the form of the final movement still remained the same, simply being more gradual in type.

Considering, now, the eighteen unusual introspections appearing in Lo.'s series, we find that only six are accompanied by the more usual forms of reaction movement; leaving a good two-thirds of the cases, in which unusual introspections involved unusual forms of movement.

Summary.—1. Lo. was a reactor of the sensory type.

2. The form of the final reaction movement was largely of the antagonistic type with the level or falling line preceding it.

3. Any marked change in the character of the attention was accompanied in most cases by a marked change in the type of the reaction movement.

Reactor W.

Reactor W. was myself. I had had considerable training in reaction experiments and had used the spring key in a number of series taken in a previous year. I was almost a practiced subject, though I had never practiced for a long time with one type of attention. In order to obtain a series from myself, it was necessary to use the other reactors as operators. They knew nothing about the technique of the experiment, and the first five or six series were therefore taken while they were being instructed in the use of the apparatus. At no time during these series did any of the men become so proficient in manipulation that I could feel entirely free from responsibility. They were constantly meeting with difficulties in which they needed assistance, either verbal or manipulatory. This could not help being a distraction. It was only with an effort that I could keep my attention on my own work of reacting.

In the reactions taken the preceding year, I had found it easier to maintain the motor rather than the sensory type of attention. For this reason I began directing my attention on the movement to be made. Series I-VI, however, are of little value as motor series, since my attention was so much taken up with assisting in the operations. Series VII is the beginning of a more normal motor series. As late as series X I stated, however, "Somewhat distracted by having to assist the operator with the apparatus from time to time." This is the last series in which such a statement occurs.

The general character of my attention was as follows: I paid very little attention to the warning signal. When the motor was started my attention turned at once to a muscular preparation of my hand and especially my forearm for the reaction movement. This type of attention and preparation became steadily more pronounced up to a certain point and then changed. The point of greatest preparation we may call the climax of attention and was

reached about two seconds after the warning, or more often two seconds after the starting of the motor. The slight variations in the time to the climax resulted from varying degrees of concentration of the attention. If the stimulus did not come at or before the climax, the attention would turn toward the stimulus. If it then came before the existing muscular preparation had had time fully to change, the reaction, though doubtless predominantly sensory, would be much faster than a normal sensory reaction without the muscular preparation. If the stimulus was still longer delayed, until the muscular preparation had quite altered, I was not ready and the reaction was slow. The final movement was in nearly every case a quick upward jerk of the forearm from the elbow, with almost no shoulder movement.

Quantitative Results,—Motor Series.—Twenty-three series of the motor type were taken, covering six weeks and averaging four series a week. The total number of reactions was 409. A summary of the reaction times is given in Table X. There is no marked effect of practice through the series. The reaction times at the end of the series are shorter than those at the beginning but there is a decided lack of uniformity in this decrease. The development seems to go forward in waves, each succeeding trough being lower than the one before. The longest steady decrease in time is from series XVIII-XXIII. In these last series the conditions were the most favorable. The average reaction time for the twenty-three series was 120σ. Omitting the first six series from the total average brings it down to 112σ. This time indicates a motor type of reaction.

The reaction times were distributed according to their frequency in the whole series and in the first and second halves of the whole series respectively (Fig. 15). Curve A shows the distribution for series I-XI. The most frequent times for these series lie in the region of 120σ and 130σ. There are a number of scattering times from 140-180σ. A large percentage of the reactions indicate, however, the motor type. The distractions already spoken of in the earlier series were responsible for their scattering times. Curve B gives the distribution for series XII-XXIII. The most frequent times in these series lie in the region

TABLE X.—*Average times and mean variations. Reactor W.*

		Chronoscope		Corrected		Movement began	
No. of Series	*Warning time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
I	1.5	152.	21.6	134.3	22.8	127.5	17.6
II	1.2	180.8	48.6	162.9	48.7	148.2	46.3
III	1.4	154.7	16.2	144.2	17.2	130.6	15.6
IV	1.4	138.3	11.7	120.4	15.4	105.2	22.4
V		142.6	17.3	130.3	16.2	116.3	18.2
VI	2.0	174.7	36.7	158.4	34.9	145.	34.1
VII	1.9	151.6	18.1	143.1	23.	131.9	18.1
VIII	2.3	137.6	21.9	120.2	23.8	111.4	26.8
IX	2.4	137.5	16.0	123.	23.3	109.6	20.8
X	1.8	138.5	16.3	115.2	18.4	111.3	20.6
XI	2.4	126.2	14.	111.4	20.8	105.7	22.
XII	2.4	128.9	8.8	115.2	10.2	115.2	10.2
XIII	2.5	143.5	17.1	123.1	14.9	122.2	13.7
XIV	1.6	140.6	16.	121.4	18.7	116.	15.5
XV	1.4	128.3	19.6	102.5	24.1	102.5	24.1
XVI	2.2	110.	13.7	84.6	18.9	77.5	22.1
XVII	2.8	134.	19.4	114.9	16.1	98.1	29.6
XVIII	1.5	138.	25.5	122.1	21.4	110.4	20.9
XIX	2.2	138.3	16.11	120.5	16.1	110.5	21.6
XX	2.0	131.3	10.6	115.8	12.	109.2	15.2
XXI	1.7	118.8	12.	100.	11.2	89.5	21.
XXII	1.7	118.2	6.88	94.	13.5	69.7	38.3
XXIII	2.0	108.8	9.9	87.2	11.5	77.7	17.4
Averages	1.8	137.9	18.02	120.2	19.7	110.4	22.2

of 100σ. There are very few times above 130σ. This curve is very sharp in form and shows a good concentration in the region indicating a motor type of reaction. It also shows a reduction in the average time between the first and second halves of the whole

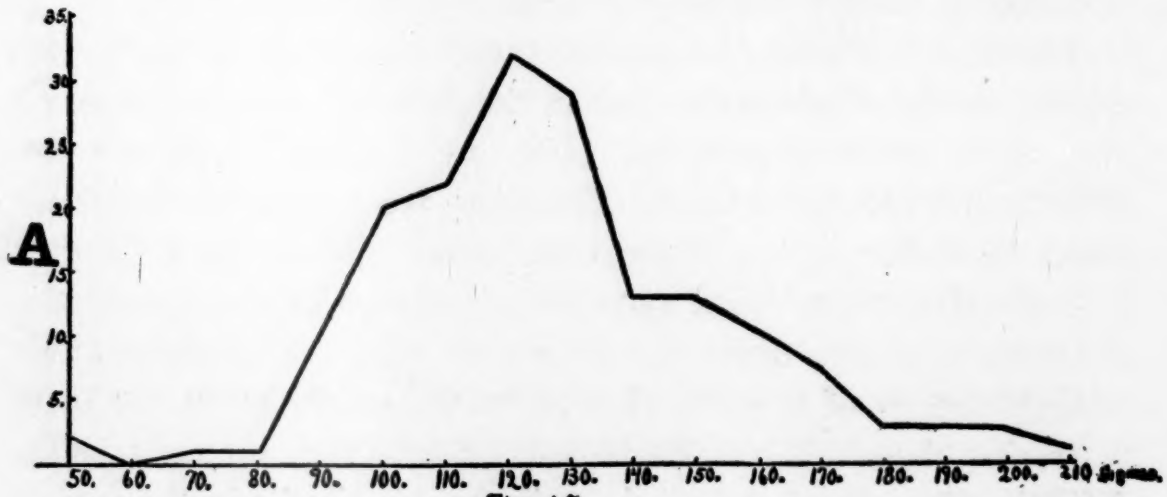
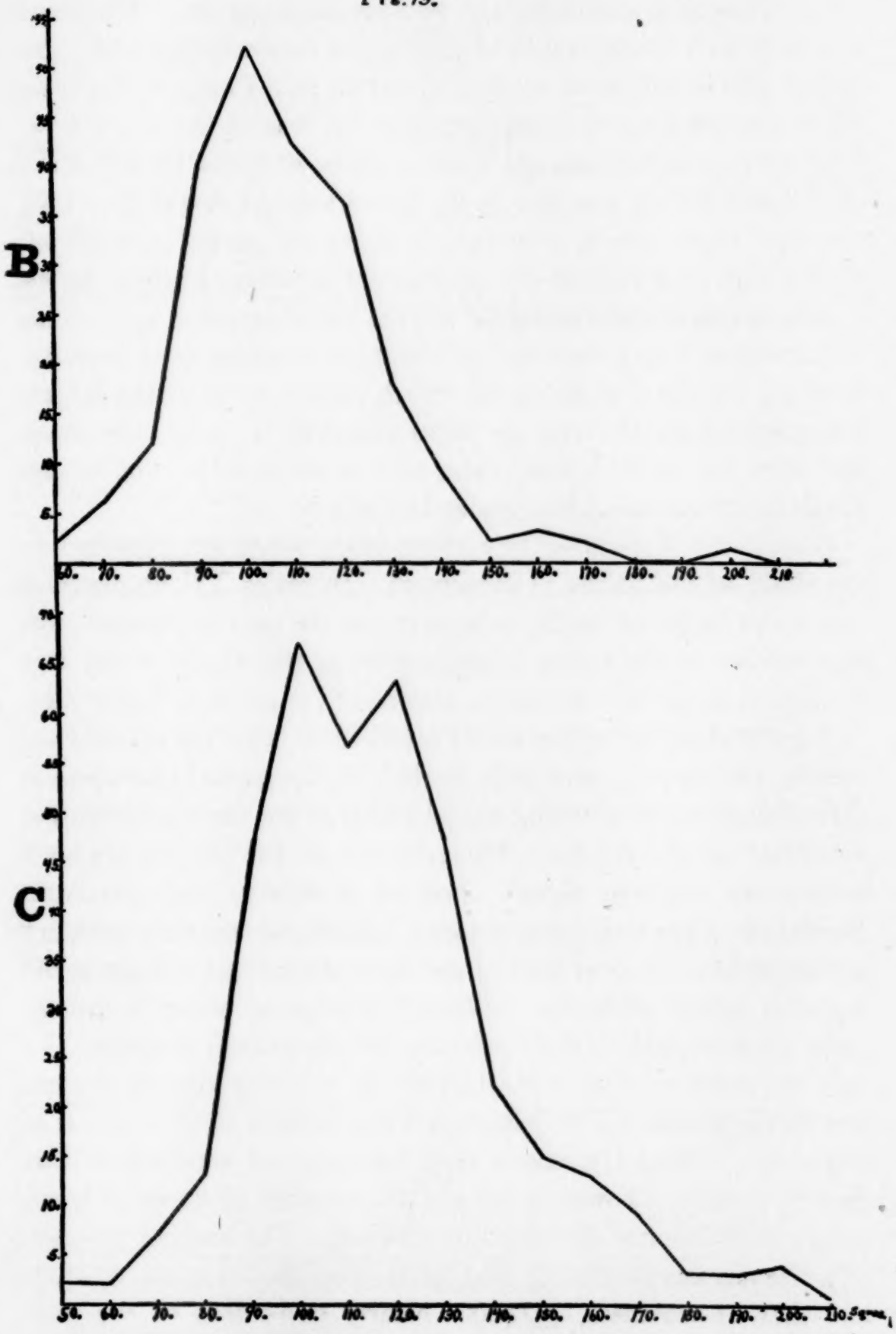


Fig. 15.

W

Fig. 15.



Reactor W.—Frequency curves of the reaction times. Curve A. shows the frequency curve for series I-XI. Curve B. shows the frequency curve for series XII-XXIII. Curve C. shows the frequency curve for series I-XXIII.

series. Curve C combines the two previous curves. The times are very well concentrated in the region between 90σ and 130σ. These curves tally with my introspections that except in the cases of distraction from without, the attention was of the motor type. The increase in the average reaction times in series II, VI, XIII, XVII and XVIII was due to the appearance of one or two long reaction times which occurred at times of partial distraction, rather than to a general altered state of attention in these series.

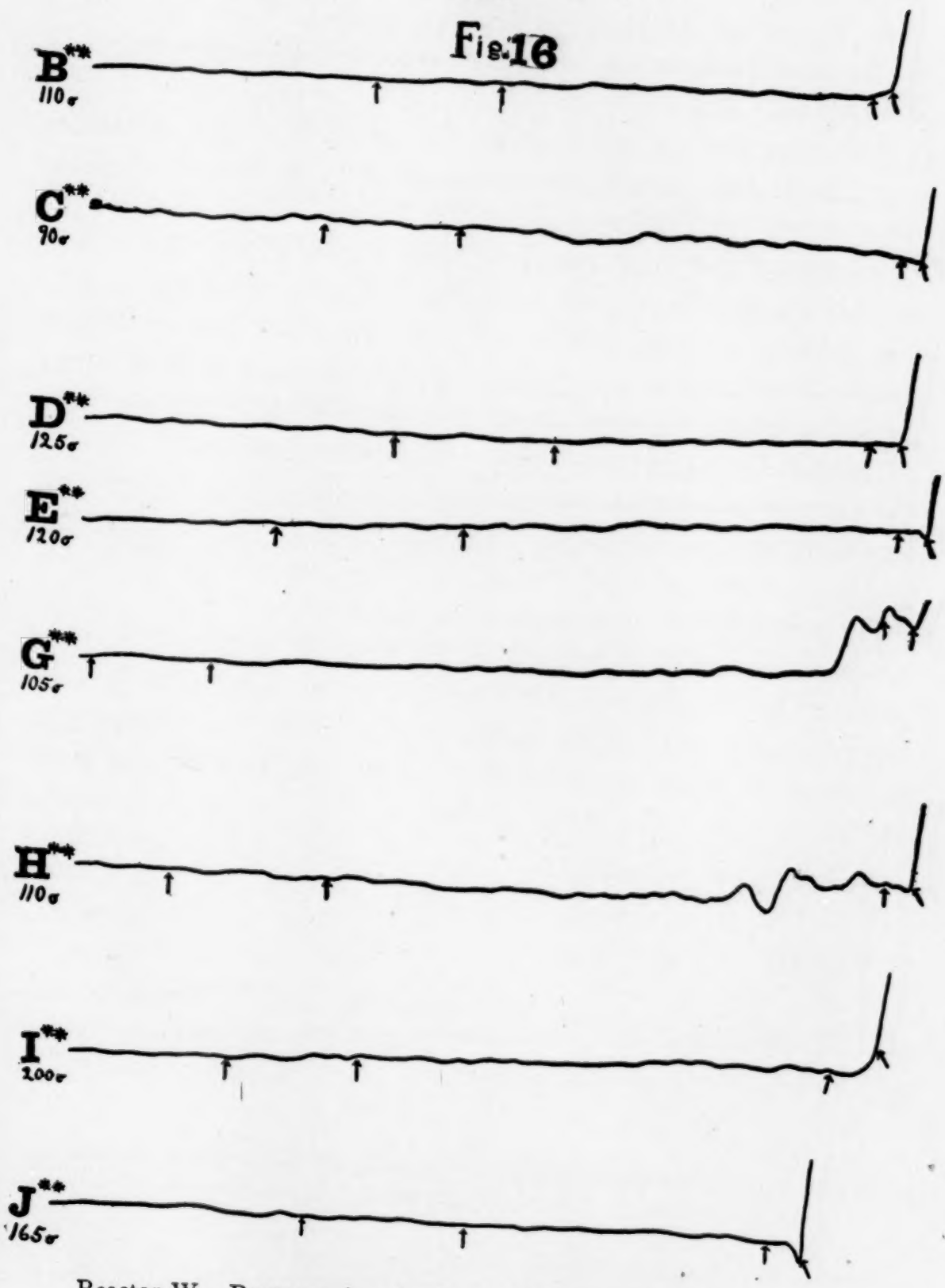
The average mean variation for the entire series is 19.7. This is somewhat larger than that of the other reactors after practice. Leaving out the first six series, which contain some of the largest mean variations, the average mean variation is 17.5. The mean variation reaches its lowest point, 10.2, in series XII. The largest single mean variation is in series II (48.7).

Qualitative Results.—Only twenty-two series are reported in the study of the forms of movement. In series XII no pressure curve was recorded, owing to an error on the part of the operator. A summary of the forms of movement in the whole twenty-two series and in the first six series, separately, is given in Table XI.

A general survey of the entire series shows that the records are usually very steady, especially in their earlier parts; that there is little change at the warning signal and that the final movement is mostly of the sharp type. Three-fourths of the records are level before the warning signal, showing a steady, even pressure. Nearly all of the remaining records, 87/409, increase the pressure in this period. In over half of the cases there is no change at the warning signal, 228/409. Where a change occurs it is usually from an increased or even pressure to a decreased pressure. In half the cases the line is level after the warning signal; in one-fourth the pressure is decreased and in one-fifth of the cases it is increased. There are only a very few cases of waviness in this period, 25/409. Towards the end the number of cases of level, steady pressure, has decreased to 166/409. The number of cases of a rise has increased, 113/409, as has also that of a fall, 97/409, and that of waviness, 43/409. Nearly two-thirds of the final reaction movements are of the sharp types shown in types B,** C,** and D,** Fig. 16. Only one-sixteenth of the total is of the

W

Fig. 16



Reactor W.—Pantograph reductions of the pressure curves.

gradual type, I.** Nearly one-fourth are antagonistic, most of them, however, of the slight type, E.** There are only seven cases of marked antagonistic reaction type, J,** and only seven of the gradual antagonistic type. There are nine double reactions of types G** and H.**

Since the first six series differed so much from the remaining ones, they were summarized independently in order to see to what extent the forms of movement found in them changed the character of the total summary (see Table XI). Their chief influence is seen in relation to the final reaction movement. Only one-sixth of the total number of sharp reactions and one-eighth of the total number of gradual reactions appear in these series (which contain, however, more than one-fourth of the reactions of the entire twenty-two series qualitatively analyzed). It is in the number of antagonistic reactions that the greatest difference, however, occurs. More than one-half, 57/97, of the antagonistic reactions appear in these six series. This leaves only thirty-five slight antagonistic reactions, two marked and three gradual antagonistic reactions outside of the first six series,—a total of forty in 301 reactions. This bears out the conclusion already reached in the cases of the earlier reactors, that fewer antagonistic and more sharp reactions occur as the reactions become more motor in type. The curve plotted in Fig. 17 shows how the

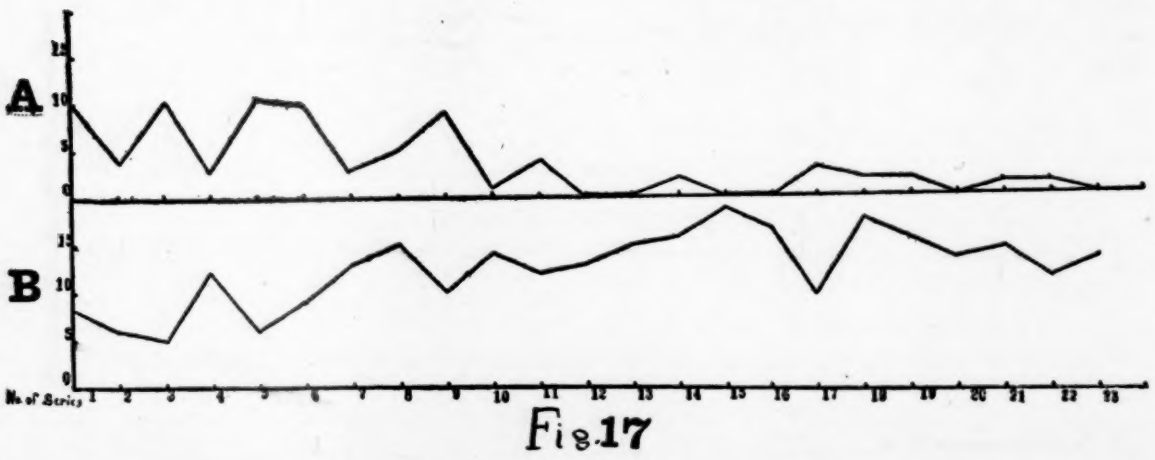


Fig. 17

Reactor W.—Frequency curves showing the relation between the number of antagonistic reactions and sharp reactions through the series. Curve A. shows the frequency of the antagonistic reactions; Curve B. shows the frequency of the sharp reactions. The number of antagonistic reactions is decreased and the number of sharp reactions is increased through the series.

Key — Series No.	I	II	III	IV	V	VI	Total I-VI		VII	VIII	IX	X
Rise before warning	2	0	0	0	1	0	3		0	0	3	0
Fall before warning	3	9	18	0	0	0	30		2	1	0	5
Level before warning	12	2	3	15	10	18	69		17	19	16	9
Wavy before warning	1	3	0	0	0	2	6		0	0	1	0
Change at warning	11	11	12	4	10	6	54		5	9	10	4
No change at warning	7	3	9	11	10	14	54		14	11	10	10
Reacted to warning	0	0	0	0	0	0	0		0	0	0	0
Marked rise after warning	0	0	1	0	0	0	1		0	0	0	0
Medium rise after warning	1	1	5	0	3	0	10	39	0	0	5	0
Slight rise after warning	5	0	12	3	6	2	28		0	1	10	1
Marked fall after warning	0	0	0	0	0	0	0		0	0	0	0
Medium fall after warning	3	1	0	0	0	1	5	16	0	0	0	2
Slight fall after warning	4	5	0	0	1	1	11		1	0	0	3
Level after warning	3	7	2	12	10	13	47		16	18	4	9
Wavy after warning	2	0	1	0	0	3	6		2	1	1	0
Marked rise towards end	0	0	3	1	1	1	6		2	1	0	0
Medium rise towards end	3	4	6	3	0	1	17	43	3	1	2	1
Slight rise towards end	5	2	6	2	2	3	20		2	1	0	3
Marked fall towards end	0	0	0	0	0	0	0		1	0	0	0
Medium fall towards end	3	1	1	1	1	2	9	17	0	1	2	1
Slight fall towards end	1	1	2	1	2	1	8		0	0	3	2
Level towards end	5	6	3	7	10	10	41		11	11	13	8
Wavy towards end	1	0	0	0	4	2	7		0	5	0	0
Reacted before stimulus	0	0	0	0	0	0	0		0	0	0	0
Sharp reaction	8	6	5	12	6	9	46		13	15	10	14
Gradual reaction	0	1	2	0	0	0	3		2	0	0	0
Slight antagonistic reaction	10	4	10	3	11	10	48		3	5	9	1
Marked antagonistic reaction	0	2	1	0	2	0	5	57	0	0	0	0
Gradual antagonistic reaction	0	1	3	0	0	0	4		1	0	1	0
Double reaction	0	0	0	0	1	1	2		0	0	0	0
No. of reactions in series	18	14	21	15	20	20	108		19	20	20	15

TABLE XI.—*Summary of forms of mo*

X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	Total I-XXIII	
0	0	0	0	0	0	1	0	0	0	0	0	1	2	10	
5	3	0	2	0	5	5	1	1	7	12	6	6	1	87	
9	15	0	14	20	15	13	16	18	12	6	14	13	15	301	
0	0	0	1	0	0	0	0	1	0	0	0	0	1	10	
4	7	0	8	6	7	7	8	8	6	6	12	12	11	180	
10	11	0	9	14	13	12	9	12	13	12	8	8	8	228	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	1	0	0	1	0	0	0	3	
0	0	0	2	0	0	0	4	0	0	0	0	0	2	23	98
1	7	0	1	6	5	4	2	5	0	1	0	0	1	72	
0	0	0	0	0	0	0	0	0	0	1	1	0	1	3	
2	0	0	0	0	0	0	0	0	4	7	4	5	3	30	79
3	1	0	3	1	1	2	1	1	4	4	6	6	1	46	
9	9	0	11	13	14	9	5	13	10	4	9	8	9	208	
0	1	0	0	0	0	4	4	1	1	1	0	1	2	25	
0	0	0	0	0	1	1	7	0	1	1	0	2	0	22	
1	2	0	2	4	4	3	3	1	2	1	1	2	0	49	113
3	2	0	2	1	3	4	1	1	0	1	0	0	1	42	
0	0	0	0	0	0	0	0	0	0	0	1	2	1	5	
1	4	0	1	2	0	2	0	2	4	5	3	3	6	45	97
2	3	0	2	0	1	3	0	2	4	7	6	4	2	47	
8	4	0	7	12	10	5	5	13	6	3	7	5	5	166	
0	3	0	3	1	1	1	9	1	3	0	2	3	4	43	
0	2	0	1	0	0	0	1	0	0	1	0	0	0	5	
14	12	0	15	16	19	17	10	18	16	14	15	12	14	276	
0	2	0	2	2	1	1	1	0	1	1	1	5	2	24	
1	4	0	0	2	0	0	3	2	2	0	2	2	0	83	
0	0	0	0	0	0	0	1	0	0	1	0	0	0	7	97
0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	
0	0	0	0	0	0	1	2	0	0	1	2	1	0	9	
15	18	0	17	20	20	19	17	20	19	18	20	20	19	409	

of movement. Reactor W.

number of antagonistic reactions decreases and the number of sharp reactions increases through the entire series.

The forms of the final reaction movement were also distributed according to the character of the attention. The sharp reactions occurred at times of normal, motor attention, except in eighteen cases. Thirteen of these exceptions came at times of lowered attention and five at times of sensory attention. A careful distribution of the slight antagonistic forms of movement shows that of the thirty-five cases which occurred in series VII-XXIII, twenty-three came at times of special effort and fast reaction times; nine occurred at times of lowered attention and three at times of very irregular pressure towards the end. The two marked antagonistic reactions occurred when there was an attempt to check a reaction before the stimulus. All of the cases of double reactions occurred with introspections of "reacted too soon." The nineteen gradual reactions were due to two causes. In nine of the cases there was an anticipation of the stimulus which resulted in an extreme preliminary rise, giving the final movement a gradual form. This type we have already noticed in the motor series of reactor M. In the remaining ten cases the attention was distracted and the movement was very slow, the time likewise being slow.

The types B,** C,** and D,** in Fig. 16, show three different forms of the sharp reaction movement. Type D** occurs with medium motor attention and medium reaction time. In such a reaction there is no extreme muscular preparation. In type C** the extreme type of motor attention is present, together with an extreme degree of muscular preparation, which takes the form of an increased innervation of the extensor muscles resulting in an increased downward pressure on the key. In type B** there is the anticipation of the stimulus accompanied by a muscular preparation of the opposite type,—a gradual inhibition of the extensor muscles resulting in a decrease in pressure on the key.

At the close of the motor series and after an interval of nearly three months, three series were taken with the attention on the stimulus. The average time for the sixty reactions was 177σ, with a mean variation of 29. The frequency curve of the

reaction times is given in Fig. 18, and shows a wide distribution of times between 130σ and 200σ, with scattering times from 110σ to 270σ. This curve is very characteristic of a sensory type of reaction in its early stages. A detailed comparison of the

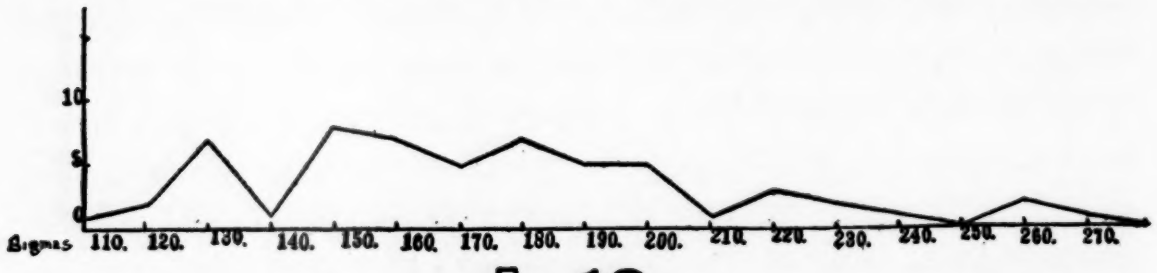


Fig. 18

Reactor W.—Frequency curve of the reaction times in the sensory series.

sensory with the motor times is of little significance because of the small number of sensory reactions. I found it very difficult to keep my attention consistently on the stimulus during these reactions, since all my training had been in the other direction. In the motor series it turned directly, when the electric motor was started, to a muscular preparation for a rapid movement. In the sensory series the attention went first to the warning signal; after the warning, to the coming stimulus; and often, after the stimulus; to the reacting finger.

Qualitative Results—Sensory Series.—The summary of the forms of movement occurring in my three sensory series is given in Table XII. This summary shows the same characteristics found in the sensory series of the other reactors and differs from my own motor series in many marked respects. In the period before the warning, in nearly two-thirds of the reactions, there is an increase in pressure, while only one-sixth is level. In marked contrast to the motor series, all but six of the records show a change in pressure at the warning signal. In the motor series more than one-half of the records were level after the warning, and of the remaining there were many more examples of decreased than of increased pressure. In this sensory series more than one-half of the records have an increased pressure after the warning, while one-quarter are level and only one-tenth have a decreased pressure. There are almost no examples of waviness in this period. Towards the end of the record nearly

one half show an increased pressure (as against less than one-fourth in the earlier series), one-quarter have a decreased pressure and one-sixth are level. No reactions before the stimulus occur. The number of final reaction movements is divided nearly equally between the sharp type of reaction, 28/60, and the antag-

TABLE XII.—*Summary of forms of movement. Sensory series. Reactor W.*

Key — Series No.	I	II	III	Total	
Rise before warning	2	3	2	7	
Fall before warning	9	14	13	36	
Level before warning	5	3	2	10	
Wavy before warning	4	0	3	7	
Change at warning	18	18	18	54	
No change at warning	2	2	2	6	
Reacted to warning	0	0	0	0	
Marked rise after warning	0	0	0	0	
Medium rise after warning	2	1	1	4	8
Slight rise after warning	2	1	1	4	
Marked fall after warning	0	1	1	2	
Medium fall after warning	3	7	2	12	35
Slight fall after warning	9	4	8	21	
Level after warning	3	6	6	15	
Wavy after warning	2	0	1	3	
Marked rise towards end	1	2	2	5	
Medium rise towards end	2	4	2	8	14
Slight rise towards end	0	1	0	1	
Marked fall towards end	2	1	1	4	
Medium fall towards end	4	4	4	12	27
Slight fall towards end	2	3	6	11	
Level towards end	3	5	3	11	
Wavy towards end	6	1	2	9	
Reacted before stimulus	0	0	0	0	
Sharp reaction	10	10	8	28	
Gradual reaction	2	3	3	8	
Slight antagonistic reaction	4	6	6	16	
Marked antagonistic reaction	0	0	0	0	24
Gradual antagonistic reaction	4	1	3	8	
Double reaction	0	0	0	0	
Reactions in series	20	20	20	60	

onistic type of reaction, 24/60, as against a ratio of three to one in the motor series. Of these antagonistic reactions 16/60 are of the slight and 8/60 of the gradual type. There are no marked antagonistic reactions and no double reactions. A comparison of the forms of movement with the introspections shows that an increased pressure after the warning and towards the end, with a slight antagonistic reaction movement, accompanies a normal sensory attention and a normal sensory reaction time. Reactions

of the delayed sensory type having times over 200σ are accompanied almost always by the gradual type of antagonistic reaction. Of the twenty-eight sharp reactions, thirteen occur at times of motor attention, five at times of delayed sensory attention, and ten at times of apparently normal sensory attention.

The difference in the effect which the warning signal had in the different series is easily explained by my difference in attitude towards the warning. In the motor series I paid little attention to the warning signal, but began my muscular preparation for the reaction with the starting of the electric motor. In the sensory series I always waited for the warning signal before turning my attention to the stimulus. This change in the direction of attention was accompanied in nearly every case by a change in the character of the pressure.

Summary.—A study of my series has shown in general the same results which we found in our study of the other reactors, namely:

1. That no change in the form of movement due to practice can be discovered as the series progresses.

2. That definite changes in the form of movement accompany changes in the direction and the amount of attention.

3. That the forms of movement found more extensively in the sensory series occur also in the motor series with sensory attention or with lowered attention.

4. That an increase in pressure throughout the record and an antagonistic reaction is very characteristic of the sensory type of reaction, while a steady pressure or a decrease in pressure throughout the record and a sharp reaction is very characteristic of the motor type of reaction.

Reactor J.

Reactor J. was a trained reactor who had little difficulty in concentrating his attention on either stimulus or movement. The attempt was therefore made to establish as clearly as possible a difference in attitude between the two types of reaction. Two series of reactions, one motor and one sensory, were taken each day, the order of sequence being varied from day to day. Ten

series, comprising 167 reactions, were had with the attention on the movement and nine series with the attention on the stimulus. Pressure records were obtained for only eight of these latter series (see Table XIV), totalling 120 reactions.

The quantitative summaries for these two types of reaction are given in Table XIII, and frequency curves for the reaction times in Fig. 19. Curve A gives the frequency distribution of the

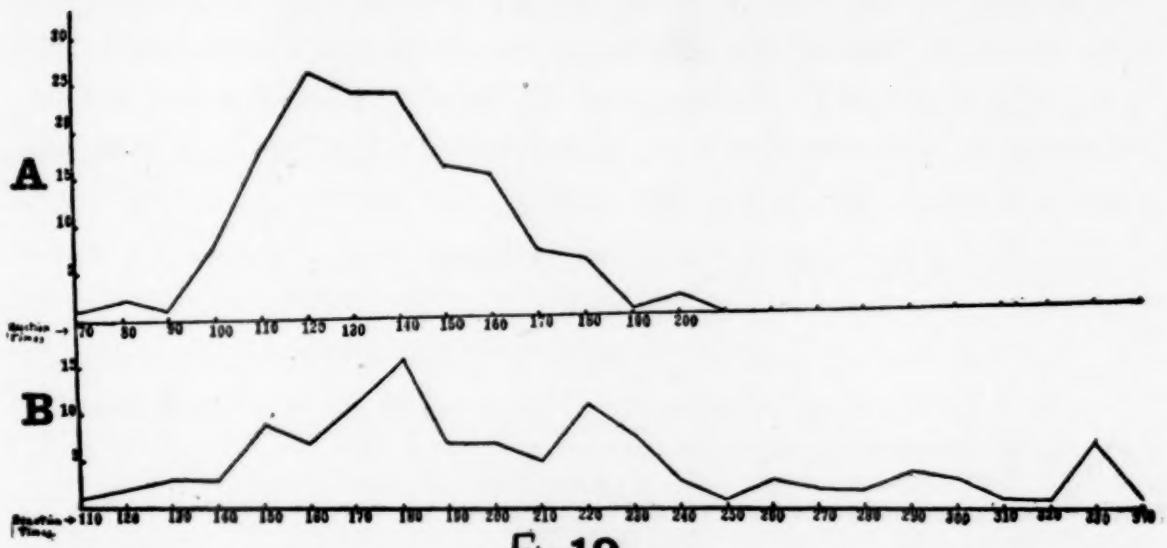


Fig. 19

Reactor J.—Frequency curves of the reaction times in the sensory and motor series. Curve A., motor. Curve B., sensory.

times in the motor series. It shows a very good concentration in the region between 120σ and 140σ. There are few scattering times either long or short. Curve B represents the frequency in the sensory series. It shows a typical curve for a sensory series in its early stages. There is a wide scattering of the times between 110σ and 330σ. There were a few even longer times, not shown in the curve. The greatest frequency lies in the region from 150σ to 230σ. The curve seems to indicate that the sensory type of reaction was not a natural one for this reactor who, however, believed it to be the more natural.

The average reaction time for the ten motor series was 135σ, with a mean variation of 20. This is a slightly longer time than that obtained in any of the other motor series. The average for the nine sensory series was 215σ, with a mean variation of 46. This is also a somewhat longer average time than that obtained from the other reactors. The large mean variation was

due to the numerous delayed sensory reactions, caused by the great absorption of the reactor's attention in the stimulus.

In the first two of the sensory series the intensity of the stimulus was varied slightly from reaction to reaction, and the reactor was asked to state after reacting whether the stimulus appeared louder or softer than normally. This was done to aid him in keeping his attention on the stimulus. In the next three series the reactor was told not to pay so much attention to the change in the intensity of the stimulus. In the last four series the intensity of the stimulus was not changed. The changes in the intensity of the stimulus had little effect on the reaction time or the character of the movement.

TABLE XIII.—*Average times and mean variations*
Reactor J.

Motor Series

		Chronoscope		*Corrected*		*Movement began*	
No. of Series	*Warning Time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
I	1.8	168	22.2	157.	24.4	140	11.7
II	1.6	152	13.8	141.8	15.2	133	9.5
III	1.5	144.2	21.1	127.	17.2	125.4	16.8
IV	1.5	160	21.1	151.4	20.1	138.8	22.7
V	1.3	157.1	18.4	139.3	25.2	126.7	26.6
VI	1.2	132.8	17.8	115.9	26.9	110.3	21.8
VII	1.2	144.4	12.8	122	26.6	120.2	29
VIII	1.4	146.2	12.2	134.4	13.3	122.5	17.5
IX	1.2	140	11.8	139.7	12.1	109.7	23.6
X	1.6	122	23.6	119.5	24.7	110.4	24.2
Averages	1.5	146.6	17.4	134.8	20.5	123.7	20.3

Sensory Series

		Chronoscope		*Corrected*		*Movement began*	
No. of Series	*Warning Time seconds*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*	*Time sigmas*	*Var.*
I	1.3	275.5	88.5	269.1	89.2	223.5	86.3
II	1.5	253.6	70	236.3	60.5	192.8	63.4
III	1.4	180	14	163.9	18.1	142.9	16.3
IV	1.4	246	44.2	237.5	45.9	183.4	39.5
V	1.3	217.5	48.7	202.4	50.5	175.8	38.3
VI	1.3	225.3	46.7	217.5	47.9	177.3	36.1
VII	1.4	222	36.4	216.5	33.8	161.9	16.5
VIII	1.3	204	41.6	199.5	40.4	177.4	40
IX	1.3	200	32	197	28.4	144.8	15.7
Averages	1.3	224.8	46.9	215.5	46	175.5	39.1

Qualitative Results—Motor Series.—A summary showing the forms of movement in the motor series is given in Table XIV. Records for fifteen of the reactions, reported in the qualitative summary, do not appear in the quantitative summary since they were reactions before the stimulus. There is a large number of cases of decrease in pressure, 74/167, as well of uniform pressure, 62/157, before the warning period, and almost no cases of increase in pressure, 9/167. There are a few cases of waviness, 22/167. There are no cases of increased pressure before the warning in the last four series. In almost every case the warning signal had a marked effect upon the amount of pressure,—a decrease lasting until the end of the record, 127/167 cases. There were but 12/167 cases in which the pressure was increased slightly after the warning signal, only a few cases of steady pressure, 22/167, and very few of waviness, 9/167. Towards the end of the record there is less uniformity. The cases of decrease in pressure are still the most frequent, 61/167, those of uniform pressure come next, 49/167, and those of an increased pressure next, 30/167. The cases of waviness have increased in this period, 28/167.

Nearly two-thirds of the final reactions are of the sharp type; one-third are antagonistic; while of the remainder, 12/167 are of the gradual type, and 4/167 of the double type. Of the antagonistic reactions 35/167 are slight, 17/167 marked, and 5/167 gradual. The introspections show that the gradual antagonistic reactions occur at times when the reactor checked a desire to react before the stimulus. The double reactions occurred when he endeavored to check a stronger desire to react before the stimulus. In two of the four cases of double reactions, the attempt was not successful. A second and even a third partial reaction occurred before the stimulus. Of the seventeen marked antagonistic reactions, fourteen occurred at times of lowered attention, one with the attention on the stimulus, and the other two when the introspections stated that the attention was good. Of the thirty-five cases of slight antagonistic reactions nineteen occurred at times of lowered attention and one with the attention on the stimulus; the remaining fifteen occurred with good motor

TABLE XIV.—*Summary of forms of movement. Sensory and motor series. Reactor J.*

Key — Series No.	Sensory I	II	III	IV	V	VI	VII	VIII	Total I-VIII		Motor I	II	III	IV	V	VI	VII	VIII	IX	X	Total I-X	
Rise before warning	9	10	9	4	2	0	5	4	43		5	17	11	12	4	6	3	1	11	4	74	
Fall before warning	3	1	1	2	3	0	0	0	10		2	0	4	2	0	1	0	0	0	0	9	
Level before warning	7	10	10	5	11	10	5	0	58		11	2	4	6	11	7	3	9	5	4	62	
Wavy before warning	1	0	0	3	4	0	0	1	9		2	1	0	0	5	6	3	0	3	2	22	
Change at warning	18	16	15	13	16	7	8	5	98		16	18	19	20	20	19	8	10	19	10	159	
No change at warning	2	5	5	1	4	3	2	0	22		4	2	0	0	0	1	1	0	0	0	8	
Reacted to warning	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	
Marked rise after warning	0	0	0	0	0	0	3	2	5		0	4	7	7	3	8	4	2	13	7	55	
Medium rise after warning	5	0	0	1	1	2	2	2	13	44	0	8	11	9	9	7	0	4	2	3	53	127
Slight rise after warning	1	3	6	2	10	2	2	0	26		4	2	1	2	2	3	4	1	0	0	19	
Marked fall after warning	3	0	0	0	0	0	0	0	3		0	0	0	0	0	0	0	0	0	0	0	
Medium fall after warning	0	1	0	0	0	1	0	0	2	30	1	2	0	1	0	0	0	0	0	0	4	12
Slight fall after warning	5	8	6	1	4	1	0	0	25		3	3	0	0	1	1	0	0	0	0	8	
Level after warning	6	9	8	6	4	3	3	0	39		12	1	0	1	4	1	0	3	0	0	22	
Wavy after warning	0	0	0	4	1	1	0	1	7		0	0	0	0	2	1	1	0	5	0	9	
Marked rise towards end	0	0	0	0	0	0	1	1	2		0	0	0	2	0	3	1	0	3	2	11	
Medium rise towards end	5	0	0	0	1	0	1	1	8	22	0	3	4	5	6	4	0	1	3	2	28	61
Slight rise towards end	0	2	4	2	2	1	1	0	12		4	2	6	5	0	3	0	2	0	0	22	
Marked fall towards end	2	0	1	0	0	0	1	2	6		0	0	0	0	0	0	0	0	1	1	2	
Medium fall towards end	3	2	0	3	3	0	0	0	11	32	0	4	0	2	0	4	0	0	3	3	16	30
Slight fall towards end	3	4	2	1	2	3	0	0	15		1	3	3	1	0	1	1	2	0	0	12	
Level towards end	7	12	13	6	10	5	6	0	59		15	7	6	5	6	2	1	2	4	1	49	
Wavy towards end	0	1	0	2	2	1	0	1	7		0	3	0	0	7	2	6	3	6	1	28	
Reacted before stimulus	0	0	0	0	0	0	0	0	0		0	0	0	0	0	1	0	0	2	0	3	
Sharp reaction	0	6	3	0	5	0	4	0	18		10	14	18	14	9	14	5	2	1	6	93	
Gradual reaction	0	0	0	3	0	0	0	0	3		0	1	0	0	2	2	3	1	2	1	12	
Slight antagonistic reaction	3	3	4	0	3	0	3	0	16		5	3	1	4	5	1	0	3	12	1	35	
Marked antagonistic reaction	15	12	12	4	12	9	3	5	72	98	5	2	0	1	1	2	0	2	3	1	17	57
Gradual antagonistic reaction	2	0	1	6	0	1	0	0	10		0	0	0	1	1	1	1	0	0	1	5	
Double reaction	0	0	0	1	0	0	0	0	1		0	0	0	0	1	0	0	2	1	0	4	
No. of reactions in series	20	21	20	14	20	10	10	5	120		20	20	19	20	20	20	9	10	19	10	167	

attention and fast reaction times. One of the cases of distraction is interesting. The operator noticed that no antagonistic reactions had occurred in the first nineteen reactions of a given motor series. Just before reaction No. 20 he asked the reactor if he had noticed any antagonistic tendencies during the series. The reactor stated that he had not. In reaction No. 20 occurred the only antagonistic reaction in the series. The reactor did not, however, record any distraction.

Summary.—We find then, that in the majority of cases a definite form of reaction movement accompanies the motor type of reaction; that in many cases in which there is a departure from this type of movement there is also a change in the character of the attention; that the form of movement in the motor reaction is a steady decrease in pressure in the period before the stimulus and a simple sharp rise in response to the stimulus.

Qualitative Results—Sensory Series.—The summary sheet of the forms of movement in the sensory series (Table XIV) shows many points in marked contrast to those found in the motor series. Of the records 58/120 are level before the warning, while only 43/120 rise slightly. There are but few cases of an increase in pressure, 10/120, and of waviness in this period, 9/120. There are not as many cases of change in the character of the pressure at the warning signal as in the motor series, although 98/120 of the records show a slight change at this point, different in type, however, from that observed in the motor reactions. Of increased pressure after warning there are in the sensory series 30/120 as against only 12/167 cases in the motor series; of uniform pressure, 39/120 against 22/167; and of decreased pressure but 44/120 in contrast with 127/167 for the motor series. These decreases in the sensory series are, furthermore, very slight. It is apparent, then, that there is a much greater tendency towards greater pressure, in the period after warning, than there was in the motor series. Towards the end, 59/120 of the records are level, 32/120 show increased and only 22/120 decreased pressure. There is almost no waviness in this period, showing little anticipation of the stimulus, 7/120.

Of the final reaction movements 98/120 are antagonistic and

of these a large majority, 72, are of the marked type; 16/120 are slight, and 10/120 are gradual antagonistic reactions. There are only 3/120 gradual reactions, all of which appear together in one series. There is only one double reaction, which occurs in the same series. After this reaction J. stated, "Motor attention." The introspections concerning the sharp reactions, 18/120, do not help us much in explaining the reason for their appearance. Twelve occur with introspections of "Sensory, fast"; five occur with introspections of "Sensory, slow"; one occurred at a time when the attention was on the movement.

Summary.—1. There is a fairly definite type of movement associated with the sensory type of reaction.

2. This movement consists typically in a uniform pressure or an increase in pressure in the period before the stimulus and an antagonistic reaction movement in response to the stimulus. When decreases in pressure occur the amount of decrease is very slight compared to that in the motor series.

Discrimination Reactions.—At the end of these series one series of the discrimination type was taken, in which the reactor was told to react to the sound of an electric hammer on his left and not to react to one on his right. The average reaction time of the nine reactions was 315σ, with a mean variation of 42. The same characteristics found in the sensory series appear in the discrimination series, but, particularly in the character of the final reaction movements, to a more marked degree. There are no sharp reactions. Seven of the reactions are of the marked antagonistic type, one is a slight antagonistic reaction, while one is a gradual reaction. In this discrimination series, then, in which the attention of the reactor was even more removed from the speed of the movement than in the simple sensory series, the reaction movement is more markedly of the antagonistic form.

IV. GENERAL DISCUSSION AND CONCLUSIONS

Smith (**5**) was interested in the form of final movement made by the reactor in response to the stimulus and in only one form of it—the antagonistic. Judd, McAllister and Steele (**3**) extended the study to an analysis and classification not only of the forms

of final movement, but also of the types of movement made in the period of preparation and adjustment preceding the stimulus. Since this work was the first of the kind, the authors concerned themselves with a determination of *what forms of movement there were* rather than with a study of the conditions under which they occurred. They did not, however, as they themselves say (p. 168), get enough records from the different reactors to yield a satisfactory classification of the forms of movement according to individuals. In the present investigation, we have endeavored to classify the forms of movement according to the individuals and in relation to types of attention and to reaction times. In almost every case the reactors themselves knew nothing in detail of the object of the investigation.

In the general discussion of results which is to follow, while we believe that the conclusions reached are based on very clear evidence, both introspective and objective, and hold, therefore, for our particular reactors under the conditions imposed, we do not, of course, claim for them universal application. They do, however, throw considerable light on the problem of "reaction types" and show the sort of results which may be expected in this field of investigation. More than this they throw light on different types of reaction in the same individual.

The main conclusions which we have reached thus far may be summarized as follows:

1. In the practice series in which the reactors received no instructions except to remove the finger from the key on hearing the stimulus, the reaction times and the mean variations were decreased. The changes in the form of the reaction movement were found to correspond with definite changes in the amount and in the direction of the attention. There was also often a marked correspondence between the changes in form of movement and those in the reaction times; the times as well as the attention varied, that is, with the form.

2. In those series in which the reactors were trained to react in the sensory or motor manner, a marked difference was found between the forms of movement in the two types of series.

a. In the typical motor reaction, the pressure was decreased

from the warning signal to the beginning of the final reaction to the stimulus; this final reaction movement was a simple, sharp rise.

b. In the typical sensory reaction the pressure was either uniform or increased from the warning signal to the beginning of the final reaction movement, which was then most often antagonistic in form.

3. The same forms of movement which appear as typical in the sensory reactions were found also in the motor series at times of lowered attention, of unintentional sensory attention or of distraction; for example, the final antagonistic reaction occurred, in motor series, when the attention deviated from a preparation for the final movement.

4. The same forms of movement which appear as typical in the motor reactions were found in the sensory series when the attention was turned unintentionally towards the movement.

5. The average correction in the reaction time which had to be made for the antagonistic form of movement was 30σ.

6. Very clear proof was found in the investigation that there were *types of reactors*. This difference in type involved not only the type of attention and the reaction time—the criteria of earlier investigators—but also the form of the movement.

In order to bring out these conclusions more clearly, we will take up a discussion of the different forms of movement occurring in the different periods of the reaction, showing how each of these forms of movement is related to the consciousness of the reactor and to the reaction times.

In the period before the warning, four types of movement were considered; a decrease in pressure, an increase in pressure, a steady pressure, and a variable pressure (giving a wavy line). Judd, McAllister and Steele found the cases of waviness the most frequent, of steady pressure next, with an increased and a decreased pressure following in the order named. The authors explained this on the ground that a wavy line represented a passive state in which no active tendency showed itself. In our records the wavy lines did not appear as often in this period as the level lines or the increases in pressure. This can be accounted for per-

haps by the different conditions under which the experiments were performed. In the earlier work the drums carrying the smoked paper were rotated by hand. The subject would then not be aroused to any definite mental attitude until the giving of the warning signal. In our investigation the drums were turned by means of an electric motor and the beginning of a given record was marked by the starting of this motor. Although the motor caused little distraction, yet it placed the reactor in a more definite attitude of expectancy from the very first. This attitude was, in the case of one reactor, so noticeable that he asked why a second warning signal was used and stated that he paid no attention to the warning given by the telephone, since the starting of the motor acted as a warning. This the writer found to be true in his own case, the starting of the motor initiating a positive state of preparation which increased in intensity as the time for the stimulus approached. With most of the reactors, however, the period before the warning was one of waiting for the warning or of bodily and mental adjustment to the conditions of the experiment in general. In our discussion of the reactors in Part III, we laid little emphasis on the forms of movement in this period because the reaction period was usually not fairly begun until after the warning signal sounded.

At the warning signal the records were classified according to whether there was a change or no change in the pressure at this point. No attempt was made to classify in the tables the different forms of change. The important thing was to note that a change took place. As we have seen, in the case of every reactor except myself, some form of change occurred in the majority of records. In the discussion of the individual reactors we have stated what the nature of it was.

Summing up the individual statements, we find that the change in the pressure at the warning signal takes two forms. In the first place the signal seems to produce a slight "start" on the part of the reactor which shows itself in the record by a sudden change in the direction of the line and a quick return to the same or a different level. This change has the appearance of a small trough caused by a slight antagonistic movement or a low wave

caused by a slight upward movement. Whether the movement is upward or downward seems to depend on the mental attitude and the muscular preparation of the reactor. If his attention and muscular attitude are already concerned with a preparation for the final reaction movement, the upward movement results. If his attention and muscles are simply concerned with holding down the key, the slight antagonistic movement results.

In the second place, the warning signal starts a definite and more permanent, though gradual, alteration in the degree of pressure, succeeding the brief trough or wave just mentioned. If the reaction be motor, this usually takes the form of a gradual decrease in pressure up to the arrival of the stimulus. If the reaction be sensory, the change becomes a gradual increase in pressure up to the arrival of the stimulus. These forms of pressure, introduced by the warning signal, receive more detailed discussions a little farther on.

In his work on Reaction Time and Attention, Bliss (**1**) quotes one of the reactors as saying: "Every warning is heard with a tendency to react." This statement was not borne out by the introspections of my reactors. It was only in exceptional cases that they were aware that the warning signal had produced any change in the pressure. Such cases occurred most often when the reactor's attention was wandering, the warning signal serving to bring back the attention suddenly to the problem before him. The records in such cases show marked partial reactions to the warning signal. Aside from introspective evidence, however, my results give an element of confirmation to Bliss's statement, since in nearly every case the warning signal *did* cause a partial reaction or a change in pressure. But the number of changes was as great for the sensory as for the motor type.

If the period before the warning may be called one of general adjustment, the periods after the warning may be called periods of expectancy. Here, as in the period before the warning, the records were divided into those showing increased pressure, decreased pressure, steady pressure and varying pressure (wavy line). A decrease in the pressure seems, as indicated above, to characterize a growing mental and muscular preparation on the

part of the reactor for the final upward movement which he is soon to make. There were 760[1] such cases of decreased pressure in the period immediately following the warning. Over one-half of these were of the slight type, and 704 of them occurred in the motor reactions.

In the cases of increase in pressure the reactor's attention, which at the outset had been turned towards holding the finger on the key, is, at warning, shifted towards the expected stimulus. The muscular preparation of holding the key down is, however, continued, the sensations of the finger on the key tending reflexly to maintain and even increase the downward innervation. It does not appear to be a definite, voluntary preparation for a quick reaction, for the reactor's attention is directed away from the movement *towards the coming stimulus*. This is shown by the fact that most of the 296 cases of increased pressure occurred in the sensory reactions. Over half of them were of the slight type.

I am inclined to accept the conclusions of Judd, McAllister and Steele, that a level line indicates "a form of expressive activity." and not mere neutral passivity. It may occur in either the sensory or motor types of reaction, but the introspections show that it is less likely to appear when the attention is distracted or lowered. Its most frequent occurrence is in the motor reactions when the subject is not preparing to react as quickly as possible. A certain amount of muscular preparation takes place, but involves only sufficient innervation to maintain a constant position. I do not suppose that we can regard such an innervation as consisting of an equal innervation of both sets of antagonistic muscles, in view of the work of Sherrington (**4**), causing a rigid equilibrium of opposing forces, but rather as an innervation of one set of muscles, in this case the extensor muscles, uniformly maintained. The evidence shows that in the motor reactions of the level type, the attention is fixed then, either on the coming final movement, the accompanying muscular preparation not being sufficient to give rise to a preliminary upward movement; or on the finger, in

[1] In the following summaries the results of two reactors are included which were omitted from the discussion because of lack of space.

which case the muscular activity is involved in an effort to hold the finger in place.

In the sensory reactions, the attention of the reactor is on the coming stimulus. Since at the outset, however, as already described, the train of motor impulses required to hold the finger on the key had been started, this downward innervation would be reflexly kept up because of the constant pressure of the key against the finger. If, as with reactor H., this upward pressure of the key did not seem to furnish a sufficiently firm foundation, the pressure of the finger would be constantly increased. If the finger felt secure upon the key, a constant and uniform pressure would result.

The total number of level lines in the period after warning was 830. We do not mean, of course, absolutely level lines, as though drawn with a ruler. There is always more or less slight change in pressure and slight undulation. The lines do not, however, show any more than just noticeable irregularities.

The introspections show that a wavy line in this period sometimes occurred because the reactor was aware of a start at the warning signal and endeavored to regain his equilibrium. Sometimes it occurred when the attention was distracted or lowered. There are 305 cases of such wavy records.

The total period between the end of the warning signal and the beginning of the final reaction movement in response to the stimulus was, it will be remembered, divided into "the period after warning" and that "towards the end," the latter referring to that part of the curve just preceding the final reaction. We will now take up this period, "towards the end." In it a rise of the curve meant in almost every case a mental and muscular anticipation of the stimulus. It is in the motor reactions that this form of movement is most characteristic. The attention of the reactor had been on making a quick reaction. If the stimulus was delayed, or if the motor attention reached a climax too soon, a gradual upward movement was begun. This movement was not fast enough to break the circuit. Such a preliminary rise did not occur as often in the sensory reaction. Where it did occur it could frequently be explained by attention on the movement.

Where this was not possible, it was found in many cases to be due to such causes as irregularities in the pressure, or waves, rather than to a positive tendency to react. In all, there were 687 cases of a rise towards the end; 519 of these occurred in the motor series.

The cases of fall towards the end occurred most frequently in the sensory reactions. Here the reactor's attention was on the coming stimulus and the muscular activity was involved in holding the finger on the key. Many of the instances preceded a final antagonistic movement in response to the stimulus. Where cases of a fall occur with the motor reaction, they were found either at times of sensory attention or distraction, or else were due to marked irregularities in the pressure. There were 512 cases of a fall towards the end, of which 274 occurred in the sensory series.

There were 937 cases of a level line towards the end. Why should there have been a greater tendency for this line here than in the period after the warning? In studying the records, one fact became readily noticeable. In many records, regardless of whether the earlier parts had risen or fallen or had been wavy, there appeared this short, level piece of record. It seems possible by comparing the pressure here with the introspections to explain this on the supposition that with the imminent approach of the stimulus both the extensors and the antagonistic flexors were innervated to the mutual degree required for equilibrium. There did not seem to be introspectively any decrease of muscular innervation, but rather a firm setting of the muscles in preparation for the coming stimulus.

Nor can the wavy lines towards the end well be related to a passive conscious state. They are the muscular accompaniment of anticipation of the stimulus and are entirely different in form from the earlier waves. These were irregular in length and in amplitude. They were due largely to irregular muscular changes of hand, arm or body. The waves occurring towards the end, however, were very uniform in length (about 100σ) and in amplitude. That these waves were due to a more extreme degree of anticipation of the stimulus (accompanied by increased muscular innervation) than accompanied the level line is shown by

the introspections and by the fact that nearly all occurred in the motor reactions where the pressure towards the end was being decreased. Such a distinction is brought out in the case of reactor J., in whose sensory reactions we find only seven cases of waviness at the end, while twenty-eight examples appear in the motor series.

What evidence can we furnish as to the type of reaction in which the premature reactions occur? Since only twenty-eight such reactions appear in the 2500 graphic records, they do not play a very important part in this investigation. Twenty-four of these twenty-eight occurred in motor reactions when the reactors showed specially strong muscular preparation and when their introspections recorded an extreme anticipation of the stimulus, usually because of a delayed stimulus. This seems to conform to the results of the majority of investigations in this field.

We turn now to a brief discussion of the final reaction movement. The sharp reaction represents the simplest possible type,—the quick lifting of the finger from the key in response to the stimulus. It occurs 1402 times, which is more than half the total number of reactions. As we have seen, this form of reaction appears most frequently in the motor series, 1144 times, leaving only 258 cases in the sensory series. Many of these latter have already been accounted for, by the introspections, as occurring when the attention had shifted to the movement. Our results do not by any means warrant the statement that a simple, sharp reaction will occur only when the attention is turned towards the movement. They do, however, mean that it is more *likely* to appear in the motor reaction. Further work with subjects more thoroughly trained may show that it will *always* occur in the motor reactions if no distractions appear.

Under this head of sharp reactions we have undoubtedly classified many different forms of movement. It represents, however, some such class as a biological species. Each of the individuals differs in some detail, but they all possess the majority of characteristics in common. These individual differences are related to the form of the movement just preceding

and to the rapidity of the movement itself. A sharp reaction terminating a fall in the line presents an entirely different appearance from one terminating a rise or a level line. A sharp reaction made in 100σ differs from one made in 140σ.

On the physiological side, we may assume, since a great majority of the sharp reactions (1144/1402) occurred in reactions of the motor type, in which the preparation was for the final upward movement, that the retractor muscles were partially innervated and the corresponding extensors partially or wholly inhibited. The motor nerve paths to the retractors were, then, the more open when the stimulus came, so that the additional innervation went directly into these motor paths, causing the quick lifting of the finger from the key. In the cases of a rising line preceding the advent of the stimulus, characteristic of motor reactions, the upward movement had actually begun, giving an emphasized preparation for the final release into a sharp reaction.

There has been a great deal of discussion as to whether the motor reaction is a brain reflex or not. Our results may seem to point towards that view, and yet we must go one step further back and not leave out of account the period of expectancy and preparation preceding the final reaction in which the particular "set" for subsequent innervations and inhibitions is given. The first step of mental and muscular preparation would, in such event, be necessary to produce the second step of "reflex" action. This explanation accounts also for the fact that the simple, sharp reaction movement occurs more often in the motor reactions. It seems reasonable, too, to expect that wherever the motor type of attention exclusively prevails, the sharp reaction movement will occur. That it did not always appear at times when the reactor thought his attention wholly on the movement might be interpreted as due to faulty introspection, although, in the absence of fuller evidence on this point, I shall not insist on such an interpretation. And yet all who have taken the part of reactor in such a series of reaction experiments know how easy it is for the attention to shift to the stimulus at the last instant in a motor reaction or to the finger in a sensory reaction. When we add to this possibility of mixed attention the many chances for dis-

traction, from either inner or outer causes, it seems almost strange that our results should be as uniform as they are.

No fine line can be drawn between what we have called the sharp reaction and the gradual reaction. It would be possible to find in the records of all the reactors a complete series showing gradual transitional forms from the most extreme form of sharp reaction to the most extreme type of gradual reaction. Only those reactions which are clearly of the gradual type have been included under this head. They may, as seen, be due to three different causes:

First, to a slow upward movement of the hand in response to the stimulus. This is the most usual type of the gradual reaction.

Second, to marked waves in the period just preceding the final movement, this movement constituting the ascending phase of one of the waves.

Third, to a rise in the line just preceding the stimulus, so rapid that it forms an obtuse angle with the final upward movement made in response to the stimulus. This latter form is rare and occurs almost entirely in the motor series of reactors M., W. and J.

The second form arises when the stimulus accidentally occurs at such a point in the already existing wavy line as to allow the final reaction movement to coincide with the upward phase of a regular wave. It is not, certainly, due to any lowering of the attention, since it often occurs when the reactor is actively anticipating the stimulus. The first form may be accounted for in two ways. It occurred most often in the first few series of each reactor when he was establishing the connections between the stimulus and the proper response. The times in these cases were long. Where it appeared in the later series it occurred at times of complete distraction or of very marked lowered attention. At such times the reactor raised his hand very gradually and the time was correspondingly lengthened. There were 204 cases of gradual reactions, 170 of these occurring under the conditions last described.

Forty-one cases of double reaction appear. Twenty-nine occur in the motor series, leaving only twelve for the sensory series. In

these twenty-nine cases the introspections show anticipation of the stimulus. The impulse to react, involving a decrease in pressure, is strong enough to start a premature reaction which is, however, realized and checked until the stimulus arrives, when the second and full reaction takes place. The varying forms assumed by this type of reaction depend on the extent to which the first reaction was allowed to go before being checked, and also on the length of time between this preliminary reaction and the stimulus. In the case of complete premature reactions there is no tendency contrary to the impulse to react that is strong enough to evoke a realization that the reaction is under way until the complete reaction has occurred.

The antagonistic reactions have now to be considered. It may be well at the beginning to call attention to a slight difference in terminology between our work and the earlier work of Judd, McAllister and Steele (**3**). The authors there apply the term "gradual antagonistic movement" to the cases of increased pressure *after the warning signal.* They speak of the reactor's preparing for the final reaction by an antagonistic movement. In this work it seemed better to confine the term "antagonistic" to the final reaction movement itself, occurring after the giving of the stimulus. Since some of the antagonistic reactions were sharp and some were gradual, the term "gradual antagonistic reaction" has been applied to the latter. We have distinguished then, three types of antagonistic reaction: the slight antagonistic reaction, involving a sharp downward movement of slight extent; the marked antagonistic reaction, involving a sharp downward movement of marked extent; and the gradual antagonistic reaction, involving a gradual downward movement, and yielding a U-shaped depression in the curve in contrast to the V-shaped depression of the other two forms. Of course, no sharp line can be drawn between the slight and the marked antagonistic reaction. Yet in the majority of reactions it was easy to distinguish between them. The slight and the marked reactions do not shade into the gradual forms.

This classification was based on the general appearance of the reaction curve, but a more careful study of these reactions in

relation to their introspections shows that they could be divided into four classes according to the conditions under which they occur.

1. *Normal antagonistic reaction:* this is usually of the slight type, occurs most often in the sensory series, and constitutes the majority of the antagonistic reactions.

2. *"Start" antagonistic reaction:* this occurs at times of extreme effort. The introspections show that the reactor's attention had been wandering or lowered and the stimulus brought the attention back with a start. It, too, occurred most frequently in the sensory series, and never in the motor series except under distraction. These antagonistic reactions are most often of the marked type.

3. *Wavy antagonistic reaction:* this is a pseudo-antagonistic reaction, occurring at the end of a period of waves. Since the reaction comes in the trough of one of the waves, which is sometimes slightly exaggerated, it has the antagonistic appearance.

4. *Gradual antagonistic reaction:* this form is due almost always to a slight attempt to react before the stimulus, which is checked just as the stimulus arrives. Had the stimulus been delayed an instant longer, this form would have assumed that of a double reaction.

Of these four classes, the wavy antagonistic reaction should doubtless be excluded, as is indicated in point 3 above. The wave after the signal is simply carried downward to a greater extent, and it would be difficult to say at what point the final reaction movement really began. It seems that only the first, second and fourth forms mentioned above may really be unambiguously called antagonistic reactions.

The experiments of Smith (**5**, pp. 56-57) to determine the cause of the antagonistic movement were repeated (see, also pp. 87-88, pp. 100-101 of the present article). Since it was not possible to change the position of the spring key without considerable modification of the apparatus, these test experiments were taken with a large tabour. In all of them the reactor was required to attend, as far as possible, to the expected stimulus.

In the first set of experiments, the tambour was placed vertically and the reactor, standing and facing at right angles to its surface, was required to place the back of his finger against it. When the stimulus occurred, he reacted by a horizontal movement with his arm involving the extensor muscles. The antagonistic phase of the movement still remained. The reactor next stood still fronting the vertical tambour which was, however, lowered so that the reactor's arm might hang at his side. The back of the index finger was in contact with the tambour. The reaction consisted of a quick backward swing of the arm and hand, involving the extensors, which is perhaps the strongest normal movement of the arm, since it is the one used by the running or walking animal. The antagonistic movement still appeared.

In another set of experiments the tambour was *inverted*. With the back of his finger against the rubber, the preliminary pressure being upward, the reactor responded to the stimulus by a simple downward movement of the hand. In the case of reactor W. the strain of keeping the hand pressed against the surface of the tambour was so great that very marked muscular waves appeared. With this procedure also the antagonistic movement still occurred, the reactors making a preliminary increased upward movement before the downward reaction.

The experiment was then tried of allowing the reactor to rest his finger passively on the surface of the tambour when the latter faced upwards. the only pressure on the rubber being the weight of the hand and arm. The reactor was instructed to react by pressing downward. In this case no antagonistic movement occurred. Again, a variation was tried by instructing the reactor to hold his finger down upon the tambour with every muscle rigid. In one instance the reactor was instructed to react to the stimulus by lifting the finger, and, in another, by pressing down. The antagonistic movement once more appeared when the finger was lifted, but did not appear when the reactor responded by pressing downward.

Let us briefly summarize, then, what we have found in regard to the antagonistic form of movement:

First, in the regular investigation the antagonistic movement occurred most often in the sensory series.

Second, when the antagonistic movement occurs in the motor series the introspections often indicate sensory attention, lowered attention or distraction.

Third, the special experiments just described showed that in a sensory series *the antagonistic reaction takes place with any set of muscles and in any position so long as the reactor, while pressing in one direction, reacts in the opposite direction.*

Fourth, that the antagonistic movement did not appear when the reactor placed his finger on an upward facing tambour and reacted by pressing downward, showed very clearly that *this movement does not occur so long as the reactor presses in a given direction and reacts in the same direction.* Titchener (**6**, p. 355) reports that he has likewise found this to be true.

Fifth, the experiments in which the reactor held his finger on the tambour with every muscle of the hand and arm rigid and then reacted, showed by the presence of the antagonistic movement that it is no accidental fact of muscular twitching, but a significant physiological fact.

Our physiological explanation of the phenomenon would then be similar to that advanced by Smith (**5**, p. 57). Where the antagonistic movement occurs, the muscles of the hand and arm have been, in our spring form of apparatus, innervated to hold the key down. When the stimulus comes, a sudden reflex innervation takes place along the line of least resistance, namely, into the open motor tract leading to the extensor muscles. This increased innervation of the muscles already innervated causes the antagonistic movement. The voluntary innervation of the retractor muscles then occurs, involving the inhibition of the antagonistic extensors, and the upward reaction movement follows.

With this explanation it is easy to see why the antagonistic movement should occur in the sensory and not in the motor series. In the sensory reaction the muscles in the hand and arm are chiefly engaged in holding down the key and when the stimulus comes the additional innervation joins in with that already predominating and causes the sudden movement in the existing direction of pressure.

In the motor reaction, contrariwise, the muscular preparation is for a quick upward movement. In many cases this movement is already begun before the stimulus arrives. When the stimulus comes, the sudden reflex innervation finds, therefore, the line of least resistance not along the motor nerve tracts to the extensor muscles, since these are already partially or wholly closed but, rather, along the more open tracts to the retractor muscles. The added innervation, reinforcing that already dominant, causes the quick upward reaction movement. Whenever the attention is turned away from the preparation for the upward movement, it is probable that the innervation of the extensor muscles is again increased, for unless there is a continued and positive effort towards an upward movement, the sensations of the pressure of the key against the finger would doubtless cause a continuous innervation of the extensor muscles in reflex response to that pressure. In this way the antagonistic movement would also occur in motor series, at times of distraction or lowered attention.

Smith gives also a psychophysical explanation of the antagonistic reaction, which we have outlined on pp. 57-58. Judd, McAllister and Steele (**3**) have criticised this on the ground that "the sudden antagonistic movements are facts of nervous mechanism rather than facts of conscious expression." True, the antagonistic movement is a fact of nerve mechanism, but it is also a fact of conscious expression since, under certain conscious conditions, i. e., sensory, it does normally occur while under others, i. e., motor, it does not. Smith stated that in the period before the stimulus the mental and muscular preparation was chiefly engaged in holding down the key, and that often under such conditions the antagonistic movement would occur, for the reasons stated above. What this investigation has added is the fact that the mental and muscular preparation is *not always* engaged in holding down the key, namely, in the motor reactions, and that in such cases the antagonistic movement normally does *not occur*.

One other fact seems to be shown by our results, and that is that reaction time work which is done with the *press reaction* will be free from the complications due to the antagonistic movement.

We must not neglect to speak of any evidence on the problem

of whether a reaction is a brain reflex or a voluntary activity (see, also p. 143). Many records occurring in the sensory series when the reactor's attention was decidedly wandering or distracted, show clearly that the reaction tends to *begin* without coincident voluntary decision. The stimulus causes a reflex "start." In these cases, however, the reaction movement is never completed rapidly unless the additional voluntary effort is added. When the attention is not brought back by the stimulus, the reaction completes itself very gradually after the first rapid start. When the attention *does* recur to the stimulus, it is brought back by a reflex start and then the much quicker and stronger voluntary reaction follows. The evidence for this is that the reactions following the return of a wandering attention to the stimulus, when it occurs, are not gradual, but sharp and quick.

If, furthermore, the theory presented to account for the antagonistic movement is a correct one, many sensory reactions would be excluded from the reflex type. The antagonistic movement itself is a reflex and in cases where this always occurred,—that is, in reactors typically sensory,—this preliminary antagonistic movement might give rise automatically to the final upward movement, so that the whole reaction would be reflex. In many cases, such as the foregoing cases of distraction or lowered attention, however, a voluntary upward movement seems necessary in addition to the reflex antagonistic movement caused by the stimulus. The preliminary "start" in such reactions seems allied to those slight partial reactions to the warning signal and to those same phenomena in the discrimination reactions in which the reactor made an involuntary movement at the wrong stimulus but did not complete the movement.

In the motor reactions, especially with reactor M., the facts appear to show an approach to the reflex. The reactor was often surprised that he had reacted and was not always sure that it was the stimulus that had set off the movement. In the period before the reaction both the character of the movement and the introspections show that a definite mental and nervous preparation had been going on,— a preparation to react as quickly as possible. The stimulus was the "last straw," so to speak, and the involun-

tary movement resulting occurred reflexly in the direction of the preparation. But this final reflex involves, as has been already emphasized (p. 143), the preparatory psychophysical "set." This agrees with those who claim that the motor reaction is a reflex act performed because of a pre-act of will.

My results show a definite correlation between the three factors, form of movement, conscious state, and reaction time. In discussing the different reactors we have shown the correlation between conscious states and forms of movement. We have shown that with each of the two typical forms of attention—attention on the stimulus and attention on the movement—there went, in the majority of cases, a definite form of reaction movement, the antagonistic reaction movement accompanying the sensory, and the sharp reaction, the motor attention. Our results have also shown a definite correlation between conscious states and reaction times, agreeing with the results of previous reaction time investigations. With the attention on the stimulus the times were longer; on the movement, shorter.

And, lastly the results have shown a correlation between forms of movement and reaction times. In the case of reactor M. with the attention fixed strongly on a muscular preparation for a quick movement, an upward preliminary movement resulted. This is undoubtedly best suited for a quick final reaction. The simple sharp reaction is also very favorable to a quick reaction time. Reactor H., whose attention was turned towards the coming stimulus, carried on at the same time an increasing muscular preparation in a direction opposite to that of the final movement; this preparation is also well fitted to give a rapid movement, but in a direction opposite to that required to complete the reaction. Hence, the antagonistic movement resulting from this type of preparation, although itself rapid, increases the total reaction time by 25σ to 30σ.

Have we not, in this fact of the preliminary increase in pressure followed by the antagonistic reaction in the sensory series and in the fact of the gradual upward curve followed by the sharp reaction of reactor M. and its explanation, come very close to explaining the difference in time between sensory and motor

reactions? In speaking of the relation of the reaction movement to the reaction time, we do not refer, of course, to different forms of movement as influencing the time with no relation to consciousness; for time, form of movement, and conscious process all vary, in great degree, together.

One question in regard to the sensory and motor reactions we have not considered. Has this investigation shown why some reactors should give motor times nearly as long as, or even longer than, sensory? In the case of reactor H. the motor times were only 3σ shorter than the sensory times. But H. interpreted the instructions "to think of the movement" as meaning a concentration of the attention on the finger in an effort to hold it down. This fact caused, therefore, more marked antagonistic reactions in the motor than in the sensory series. Such a tendency may appear in the case of many reactors of the sensory type, and would account for a part of the longer times in their so-called motor reactions. The rest might be adequately accounted for by the distraction caused by the unusual direction of the attention.

This investigation has shown very clearly that there are individual types of reactors. Reactor M. adopted the motor attitude from the first. He liked the spring key because it allowed him to prepare for the final movement by raising the hand before the stimulus. He did not like the electric key, since this natural tendency to prepare for the final reaction movement could not be carried out without breaking the circuit. This fact changed his whole attitude, causing him to think of holding his finger down on the key, and inhibited the natural tendencies, increasing the reaction time nearly 50σ.

Reactor H., on the other hand, adopted the sensory form of attention from the first. He did not like either the spring key or the tambour, because they did not furnish a firm foundation from which to start. *Why* a firm foundation was needed H. could not tell. The reason was without doubt connected with the necessity of checking an antagonistic movement, already begun, in order to begin the upward movement. H., in contrast to M., liked the electric key because of the feeling of security that it gave. H. believed himself to be executing much faster reactions on this

key, while in reality his reaction times were increased by nearly 30σ. The mean variations were decreased by one. The reason for this increase in time is not clear. It may have been connected with the fact, which H. recorded in his introspections, that this key required more pressure, or it may be that this form of key, in interfering with the extent of the possible antagonistic movement increased the time in some way. If this latter suggestion were true, then the error due to the antagonistic movement would be greater in the electric form of key than in a key which allowed for the natural movement, increasing, thus, the total reaction time. Reactor M. stated in one introspection that the electric key required more pressure and that more time was taken in overcoming this pressure. Such a statement may throw some light on the problem.

Of the other reactors, E. and W. were distinctly motor in type. As we have shown, the reactor's type is revealed by his attitude during the experiment, which influences both the form of movement and the time of reaction. With E. these all changed, showing that sometimes a type develops, even without instructions. The conditions at first may be so new and strange that the characteristic type is concealed. As adaptation to these sets in, the natural type emerges—in E.'s case, the motor type.

It would be interesting to follow the changes in the form of movement, in correlation with the attitude and the times, which accompany extended practice in both kinds of reactions. If it is true that the types first separate and then approach each other, what part does the form of movement play in this process?

Though quite definite individual characteristics appear in the pressure curves of the different types of reactions, this investigation has shown that the forms of movement are more closely connected with general attitudes and types of attention than with individual characteristics. In their earlier work Judd, McAllister and Steele found it possible to change the character of the movement at once by changing the character of the task required. This we also found to be true, not only with a change in apparatus, but when only a change in attention was involved; good examples of this may be found in the reactions of J. (Table XIV).

We likewise found, as in the earlier work, that different forms of movement suddenly made their appearance and are scattered through the series at random. We have been able to connect these with variations in attention. This being the case, it is manifestly in order to take graphic records of *all* reactions before anything of importance can be inferred from the times themselves; and as we have shown, even if the introspective evidence is perfectly clear and valid, many radical changes in movement go entirely unnoticed by the reactor. This is specially true in the sensory reactions where the attention is turned away from the movement.

Our results give little help to the experimenter who asks for some easy way of determining the type of attention or the form of the movement by a study of the mere reaction times. The mere fact that a reaction time is longer than the average does not prove that it is caused by an antagonistic movement; neither does the fact that it is shorter show the absence of an antagonistic movement.

Such results as ours show, finally, very clearly the need of subjects carefully trained in introspection with which to supplement the graphic records. If it is answered that psychology is as much interested in the untrained and unpracticed subject as in the trained subject, we agree, but in order definitely to settle this question of the correlation of forms of movement with conscious attitudes or with types of reactors, will it not be necessary *first* to use trained subjects, so that we can be sure that the form of movement studied really *did occur under the conditions imposed?* Such a preliminary study would make much easier the study of the untrained subject.

Future work should be, therefore, *first,* along the line of perfecting apparatus; and *secondly,* experimentation with subjects thoroughly trained in introspection and possessing definite characteristics.

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